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FLUORIDE POLLUTION IN THE FLATHEAD COUNTY, MONTANA

PEDCo-Environmental Specialists, Incorporated

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FLUORIDE POLLUTION IN THE FLATHEAD COUNTY, MONTANA

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
Air and Water Programs Division
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An aluminum reduction plant began operation in Flathead County, Montana, near Columbia Falls in 1955. A consequence of the electrolytic reduction process used in the plant is the generation of gaseous and particulate fluoride air pollutants. In 1957 foliage injury symptomatic of excessive accumulation of fluoride was identified in the vicinity of the plant. Following plant expansions, visible injury to flora was detected in the southwestern part of Glacier National Park, which at its nearest point is about 6 Miles northeast of the aluminum plant. The report discusses Meteorological and air quality investigations conducted by the Environmental Protection Agency, along with extensive investigations of fluoride accumulation in indigenous vegetation in the area.

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SUMMARY

An aluminum reduction plant began operation in Flathead County, Montana, near Columbia Falls in 1955. A consequence of the electrolytic reduction process used in the plant is the generation of gaseous and particulate fluoride air pollutants.

In 1957 foliage injury symptomatic of excessive accumulation of fluoride was identified in the vicinity of the plant. Expansions of the aluminum plant in 1965 and 1968 resulted in increased emissions of fluorides to the atmosphere. Following the second expansion, visible injury to flora was detected in the southwestern part of Glacier National Park, which at its nearest point is about 6 miles northeast of the aluminum plant.

In 1970 the National Park Service, U.S. Department of the Interior, requested assistance from the National Air Pollution Control Administration, a predecessor of the U.S. Environmental Protection Agency, in assessing the effects of airborne fluorides on flora and fauna of the Park. Much of the land of Flathead County is National Forest. The Forest Service, U.S. Department of Agriculture, which had first

identified foliar damage in the vicinity of the aluminum reduction plant in 1957, had continued its concern for injury to vegetation in the national forest lands surrounding the plant. The result of the combined interests of these several Federal agencies was the initiation in 1970 of cooperative studies of the distribution of fluoride pollutants and their effects on flora and fauna in the Columbia Falls-Glacier National Park region of Flathead County.

Field study projects were undertaken by the Environmental Protection Agency, the Forest Service, and the Environmental Studies Laboratory of the University of Montana as contractor to the EPA. Assistance in the studies was given by the National Park Service, the Montana State Department of Health and Environmental Sciences, and other institutions and individuals. Reports have been published on the studies of the Forest Service.[1,2] the Environmental Protection Agency,[3] and the Environmental Studies Laboratory.[4] This report summarizes all of these earlier reports concerning fluoride pollution in Flathead County.

Meteorological and air quality investigations were conducted by the Environmental Protection Agency. The prevailing upper-level winds in the area during the summer are from the southwest. Daytime surface winds passing the aluminum plant, like the upper-level winds, are generally from the southwest in up-valley flow; the direction tends to reverse to down-valley flow during nighttime hours. Air quality was assessed in the summer of 1970 by measurement of fluoridation rate with sodium formate papers at almost 40 locations in the study area, and by companion volumetric measurements of gaseous and particulate fluoride concentrations in air at four locations. Indices of fluoride pollution decreased rapidly with increasing distances from the aluminum plant in all directions except to the northeast, where elevated fluoridation rates are found 10 or more miles from the aluminum plant; these high rates probably are due to the prevailing southwesterly daytime winds and the higher elevations of exposed sites northeast of the plant.

Extensive investigations of fluoride accumulation in indigenous vegetation in the study area were conducted in 1970, and limited followup surveys were done in 1971. The most comprehensive investigations were done by the Forest Service and by the Environmental Studies Laboratory; the Forest Service sampled on a radial plot system, and the Environmental Studies Laboratory on the basis of identified sampling zones. Both investigations yielded very high values, hundreds of parts per million of fluoride, in foliage collected nearby the aluminum plant, and both demonstrated excessive levels of fluoride in vegetation representing an area of more than 300 square miles around the plant (334 square miles from the Forest Service radial plot system, 375 square miles from the Environmental Studies Laboratory sampling zone system). The geographic patterns of location of samples showing excessive levels of fluoride accumulation were similar for both investigations and were consistent with patterns of fluoridation rates as determined by the Environmental Protection Agency.

Special studies involving the use of plant exposure chambers were done by the Environmental Protection Agency. Plants brought from regions remote from Flathead County were grown for several months in three pairs of chambers located at selected sites in the study area. One chamber of each pair was equipped with devices to remove particulate and gaseous fluoride from the air entering the chamber; in the other chamber, plants were exposed to unfiltered ambient air. Plants from the chambers with unfiltered air generally yielded 2 or 3 times more fluoride than did their counterparts in the clean air chambers. Since the plants were grown without influence of local soils and rainfall, the differences in fluoride accumulation can be attributed to fluorides in the ambient atmosphere.

All agencies, the Environmental Protection Agency, Forest Service, and Environmental Studies Laboratory, reported detection of visible injury and histological changes in foliage of indigenous vegetation consistent with fluoride injury. The Environmental Studies Laboratory identified histological changes attributable to fluoride injury in conifer needles that on subsequent analysis yielded only moderate fluoride concentrations; this finding demonstrates that histological changes are not limited to massive accumulations of fluoride.

Although most of the vegetation analyses were performed on coniferous foliage, all investigations yielded data showing accumulation of excessive levels of fluoride by other species of vegetation, including grasses and woody shrubs, which are foraged by animals.

The studies also revealed that fluorides accumulate in plant tissues other than foliage. Work of the Environmental Studies Laboratory demonstrated that fluorides accumulate in pollen, stems, and terminal buds. Fluorides absorbed from the air by the foliage of plants do not remain entirely in the foliage tissue, but a portion moves into other tissues such as stems and reproductive material.

Indigenous wild animals, including mammals, birds, and insects, were collected from the study area and examined for fluoride accumulation. In most cases femur bones of mammals and birds were analyzed; insects were oven-dried and analyzed in total. Excessive accumulations of fluorides, up to 30 times greater than concentrations in tissues from control animals, were found in animals collected throughout much of the study area. Among the insects, pollinators yielded the highest levels of fluoride accumulation. Cambium feeders also demonstrated elevated fluoride content, a further indication of the translocation of fluorides from leaf tissues to other portions of plants.

In general, when elevated levels of fluoride were found in animals, they were relatively higher than those in forage from areas in which the animals fed. For example, in one area in which the concentrations of fluoride in forage were 2 or 3 times greater than those in control vegetation, the concentrations of fluoride in femur bones of snowshoe hares collected there were almost 20 times greater than those in controls. This finding illustrates the progressive increase in the food chain for an accumulative agent such as fluoride.

Emissions from the aluminum plant were reported to have been reduced by a factor of 2 or 3 between the collections of 1970 and those of the summer of 1971. Foliage specimens were collected in 1971 from the same trees or the same sampling plots that were sampled in 1970. Where reductions in the fluoride concentrations in coniferous needles of the same age were observed for the 2 successive years, the decrease was generally less than proportionate to the reported reduction in emissions. This was particularly true at sampling locations 6 to 8 miles downwind from the plant. This finding suggests that the accumulation of fluorides by vegetation, with the associated insult to fauna of the region, will continue with continuing fluoride emissions at the rates that prevailed in 1971. Further reductions in emissions from the aluminum plant will undoubtedly be required if cessation of fluoride injury to flora and fauna of Flathead County is to be achieved.

INTRODUCTION

An outstanding feature of Flathead County in northwestern Montana is Glacier National Park. The Park straddles the Continental Divide from the Canadian border southward for 60 miles. It includes some of the most spectacularly rugged mountain country in North America. Mountain peaks rise well above 10,000 feet in the Park; some of these peaks are always snow-covered, and glaciers are permanent features of some high slopes. This Park, established in 1910, is ninth oldest of the 38 National Parks, and with an area of more than a million acres, is fourth largest. Some 1,400,000 persons visit the Park each year.

Flathead County, for several miles to the south and west of Glacier National Park, is largely National Forest. Ranching and lumbering are major activities in the area.

Some 8 miles southwest of Glacier National Park at its nearest point is the town of Columbia Falls. Between Columbia Falls and the Park, about 2 miles northeast of the town, is a large aluminum reduction plant of the Anaconda Aluminum Company. In this plant alumina, dissolved in molten cryolite and calcium fluoride, is reduced electrolytically to aluminum metal. A consequence of this process is the generation of air pollutants, which include particulate and gaseous fluorides. Vegetation absorbs gaseous fluorides from the air. These fluorides accumulate in plant tissue and even in small excess are toxic to plants and to the animals in the food chains that utilize these plants.

The aluminum reduction plant began operation in 1955. Officials of the Anaconda Aluminum Company asserted then that injury to indigenous flora and fauna would be negligible. As early as 1957, however, Ponderosa pine trees in the vicinity of the plant were dying; after inspecting them, a Forest Service pathologist expressed his opinion that the injury was caused by fluorides emitted from the aluminum plant. The plant was expanded in 1964-65 and again in 1967-68. Following the second expansion in 1968, dead and dying trees were observed over the entire west face of Teakettle Mountain, which is directly east of the aluminum plant. Other areas around Columbia Falls, east of Teakettle Mountain, and even areas in the southwestern part of Glacier National Park, which at its nearest point is about 6 miles northeast of the aluminum plant, also exhibited visible damage to flora.

The Anaconda Aluminum Company reported that fluorides were emitted during 1969 and early 1970 at the rate of nearly 7600 pounds per day (lb/day), but that emissions were reduced to about 5000 lb/day by September 1970. By early May 1971, emissions were reported to be 2500 lb/day.

The Flathead National Forest occupies much of the non-Park area surrounding Columbia Falls and the aluminum reduction plant. The Forest Service, U.S. Department of Agriculture, began an evaluation of fluoride damage to flora on these National Forest lands in 1969. With visible evidence of damage to vegetation within Glacier National Park as well, National Park Service officials, in 1970, requested the assistance of the National Air Pollution Control Administration, now a component of the Environmental Protection Agency (EPA), in assessing the effects of airborne fluorides on vegetation and wildlife in the Park. The requested field investigations were conducted in 1970. As part of its studies, EPA contracted with the Director, Environmental Studies Laboratory, University of Montana, to investigate the accumulation of fluoride and its pathological effects in various flora and fauna in the Columbia Falls and Glacier National Park area. In cooperation with the overall study effort the Forest Service extended its investigation to include areas in the southwestern portion of Glacier National Park nearest Columbia Falls and the aluminum reduction plant.

The various investigations conducted by the survey participants were designed to provide information on several different aspects of the effects of atmospheric fluorides. The study activities were divided among the participants, and responsibilities were assigned to prevent duplication of effort and to ensure as complete an assessment as possible within the available study resources.

The Forest Service investigations emphasized accumulation of fluorides in vegetation and insects. A system of plots located at varying distances on predetermined radii extending from the aluminum plant was used for the collection of vegetation and insect samples. Visible damage appearing on vegetation samples was measured, and chemical analysis for fluoride accumulation was made. Insects were analyzed for fluoride content and were monitored for discernible differences in population levels attributable to excessive fluoride exposure. Two reports of these studies have been published.[1,2]

The EPA studies involved determining the predominant patterns of movement of airborne fluorides from the aluminum plant to Glacier National Park, measuring ambient concentrations of fluorides in the Park, and assessing effects of fluorides on indigenous flora within the Park. In addition, selected plants that are sensitive to fluorides were exposed to filtered and unfiltered ambient air in special plant shelters at selected locations within the study area. In the conduct of its investigations the EPA was assisted by the National Park Service, Montana State Health Department, the Environmental Studies Laboratory of the University of Montana, and other consultants. Results of the EPA studies have been published.[3]

During the summer and fall of 1970 the Environmental Studies Laboratory of the University of Montana conducted extensive sampling of flora and fauna in a 400-square-mile Columbia Falls-Glacier National Park study area. Approximately 2000 plant tissue specimens were collected and analyzed for fluoride content. Fluoride analyses were also performed on femur bones of almost 400 indigenous wild animals collected from the study and control areas. Histological examinations were made on selected samples, and investigation of translocation of fluorides in plant tissues were conducted. The report by the Environmental Studies Laboratory on this highly comprehensive work has been summarized and published by the EPA.[4]

The report presented here is based upon, and draws freely from, the reported work of the Forest Service, EPA, and the Environmental Studies Laboratory of the University of Montana. Its purpose is to assemble into a single document a summary of results of the cooperative efforts of the various agencies. Portions of the parent reports, cited above, are reproduced throughout this report; the original reports are referenced specifically only for the identification of data.

DESCRIPTION OF THE AREA

The geographic area of the studies described here lies within Flathead County in northwestern Montana. Flathead County has an area of more than 5000 square miles and a 1970 population of about 40,000 persons. Kalispell, the County seat, has a population of about 10,000; two other major towns in the County, Whitefish and Columbia Falls, have populations of about 3300 and 2700, respectively. Most of Flathead County lies within the boundaries of the Flathead National Forest and Glacier National Park. The County's major year-round economic activities are ranching and lumbering, with their associated service industries, and operation of the Anaconda Aluminum Company's aluminum reduction plant at Columbia Falls. Tourism, a seasonal activity, is also of major economic significance. Out-of-state tourists spend an estimated $100,000,000 each year in Montana; Glacier National Park, lying largely within Flathead County, is one of the State's major tourist attractions.

The major geographic features of the area are the rugged mountains, which rise to the Continental Divide along the eastern boundary of Flathead County, and the Flathead River system, which drains to Flathead Lake, a natural lake of some

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200 square miles area located southeast of Kalispell. These features are identified in the map of Figure 1.

From peaks well above 10,000 feet, the mountains pitch down to the river valley at an elevation of about 3000 feet. The Flathead River system forms the western boundary of Glacier National Park. Its drainage area is subdivided into an "upper valley" with narrow tributary canyons and swift streams, and a "lower valley" more than 15 miles wide, through which the river meanders to Flathead Lake. The river leaves the upper valley through Badrock Canyon, which also constitutes the south wall of Teakettle Mountain. The Anaconda Aluminum Company reduction plant is situated a mile down-river from Badrock Canyon between the river and the west face of Teakettle Mountain.

Although there are several ranches in the upper valley, the area is primarily Park and National Forest land with a limited road system along the main streams. The lower valley is relatively broad and flat, with a road network that follows section and quarter-section survey lines. Agricultural activity is more extensive in the lower valley than in the upper valley.

The climate of the Flathead River drainage area is classed as Alpine with a strong maritime modification. The range of climate extends from that of the permanently snow-covered peaks to that found along the shores of Flathead Lake, where small fruit orchards flourish in a 3-month frost-free belt.

The higher mountains are estimated to receive as much as

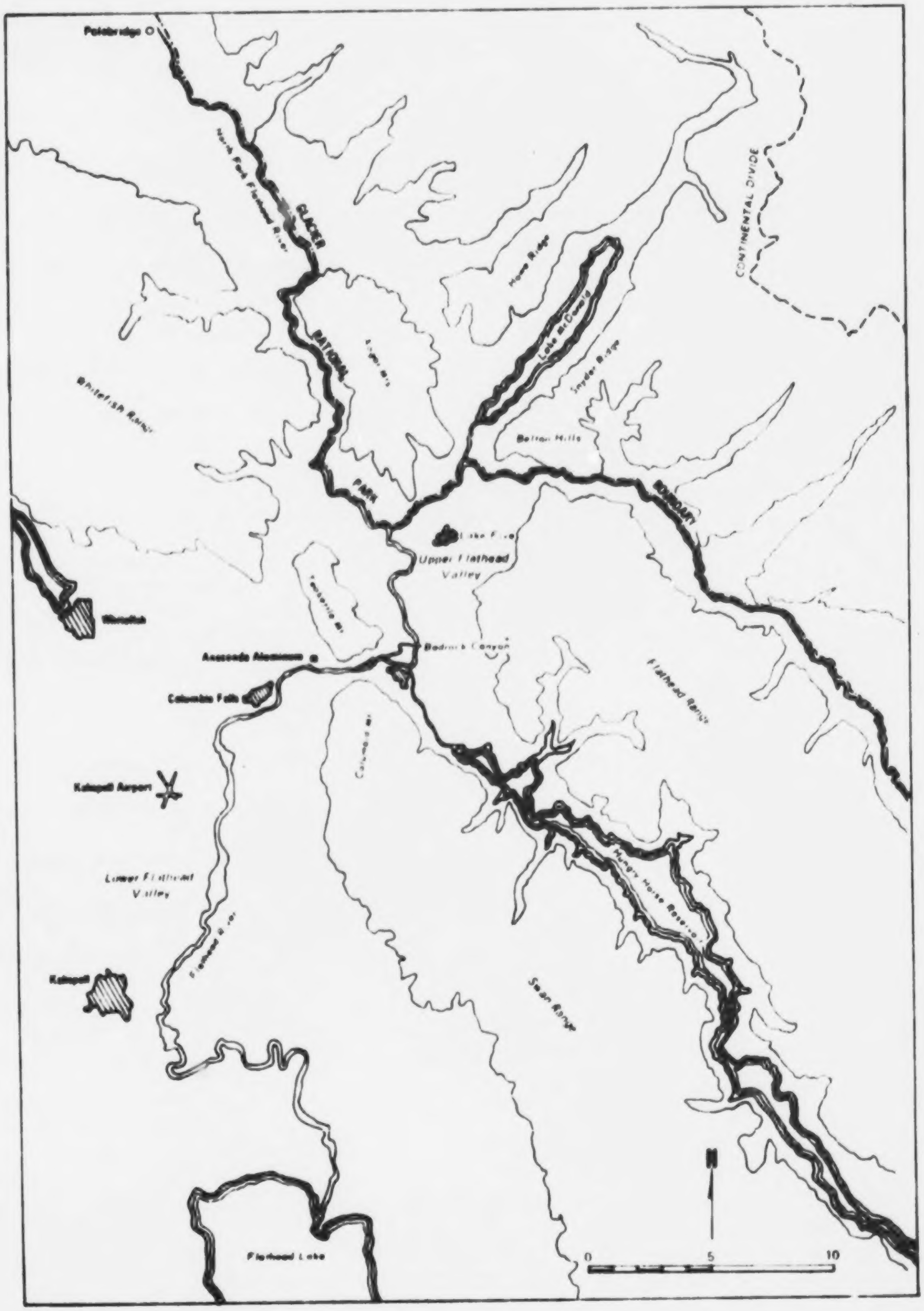
Polebridge
North Fork Flathead River
GLACIER
NATIONAL
PARK
BOUNDARY
CONTINENTAL DIVIDE
Howe Ridge
Lake McDonald
Apgar Mts
Snyder Ridge
Belton Hills
Whitefish Range
Lake Five
Upper Flathead Valley
Teakettle Mt
Whitefish
Anaconda Aluminum
Bedrock Canyon
Columbia Falls
Flathead Range
Columbia Mt
Kalispell Airport
Hungry Horse Reservoir
Lower Flathead Valley
Flathead River
Kalispell
Swan Range
N
0
5
10
Flathead Lake

Figure 1. Orientation map showing major features of the study area portion of Flathead County, Montana.

150 inches of precipitation annually, primarily as snow, on their west-facing slopes. Snow depths in excess of 10 feet accumulate during the winter, and, while the shores of Lake McDonald (3100 feet above MSL) are snow-free by May, drifts may remain on the lower north-facing mountain slopes into August. Snow-covered glaciers are permanent features of the high slopes of some peaks.

Significant differences in temperature, precipitation, and wind flow are associated not only with elevation, but also with the orientation of the mountainsides, the proximity of ridgelines, and the location of the larger lakes relative to a given location. Flathead Lake, because of its size and depth, normally contains a large open water area throughout the winter. This heat source exerts a strong modifying influence on the climate of the lower valley.

Selected climatological summary data for the area are presented in Table 1. Marias Pass, located at the southern boundary of Glacier National Park, is included in the Table because it has approximately the same elevation as the saddle in Teakettle Mountain and the Apgar Lookout overlooking West Glacier, both of which are terrain features important in wind movement over the aluminum plant toward the Park. Although the Marias Pass is well removed from the area of study, its climatic data are thought to be representative of these similarly exposed locations under study. Much of the mountainous portion of the study area, however, is higher than Marias Pass and has a correspondingly shorter growing season and a more severe climate.

Table 1. CLIMATOLOGICAL CHARACTERISTICS OF GLACIER NATIONAL PARK REGION.

(NORMALS, MEANS, AND EXTREMES BASED ON APPROXIMATELY 30 YEARS OF RECORDS)

Station and Elevation, ft MSL	Temperature, °F				Mean No. of Days that temperature remained ≤32°F		Precipitation, inches		
	Mean Daily		Extremes of Record				All Forms, mean	Snow and Sleet	
	Max.	Min.	Max.	Min.	Max.	Min.		mean	monthly max.
			April						
Kalispell 2965	57	31	81	14	0	20	1.04	2.4	8.1
West Glacier 3145	54	30	80	3	a	21	2.00	4.5	24.0
Polebridge 3690	53	25	86	-12	a	26	1.55	4.1	24.8
Marias Pass 5213	45	23	74	-30	3	26	2.93	25.5	87.0
			July						
Kalispell	84	48	104	32	0	a	1.04	0	0
W. Glacier	80	47	98	32	0	a	1.48	T[b]	T[b]
Polebridge	81	41	101	27	0	2	1.18	0	0
Marias Pass	73	40	93	26	0	4	1.35	T[b]	T[b]
			October						
Kalispell	56	32	81	15	0	21	1.24	1.1	9.9
W. Glacier	53	33	79	15	a	16	2.57	2.0	28.0
Polebridge	55	27	85	-21	a	23	1.84	3.1	16.5
Marias Pass	49	29	82	-7	2	21	3.14	11.9	61.0
			January						
Kalispell	28	12	50	-26	17	30	1.37	20.0	34.8
W. Glacier	28	14	49	-37	18	30	2.99	36.6	74.5
Polebridge	28	7	51	-46	19	30	2.63	32.8	91.2
Marias Pass	23	7	48	-55	23	31	4.17	44.0	123.0
			Annual						
Kalispell	55	31	105	-35	52	195	15.42	67.3	49.7
W. Glacier	53	31	98	-37	53	192	29.11	134.2	74.5
Polebridge	54	25	101	-46	56	238	22.32	119.6	91.2
Marias Pass	47	25	96	-55	94	247	38.29	251.3	123.0

a Less than 12 hours
b Trace

ATMOSPHERIC EMISSIONS FROM THE ALUMINUM SMELTER

THE PROCESS

The basic process used for producing raw aluminum metal in all plants in the United States consists of the electrolytic dissociation of alumina (Al_2O_3) dissolved in a molten bath of cryolite (Na_3AlF_6) and fluorspar (CaF_2). Oxygen released in this process reacts with a carbon anode to form carbon dioxide and some carbon monoxide. The molten aluminum settles to the bottom of the cell, directly above the cathode.

The electrolysis is performed in a device known as a pot, which consists of a carbon crucible housed in a steel shell. The carbon crucible serves as the cathode and another carbon mass serves as the anode. The configuration of the anode distinguishes the type of pot; there are three types in use, the pre-baked anode, the vertical stud Soderberg anode, and the horizontal stud Soderberg anode. In the pre-baked configuration the anode consists of blocks of carbon paste that are pre-baked in an oven prior to use. These anodes are replaced as units as they are oxidized in the cell. The Soderberg configurations use continuous carbon anodes. In these, carbon paste is added periodically to the anode assembly and bakes as the anode is oxidized and the assembly moves downward into the hot cell.

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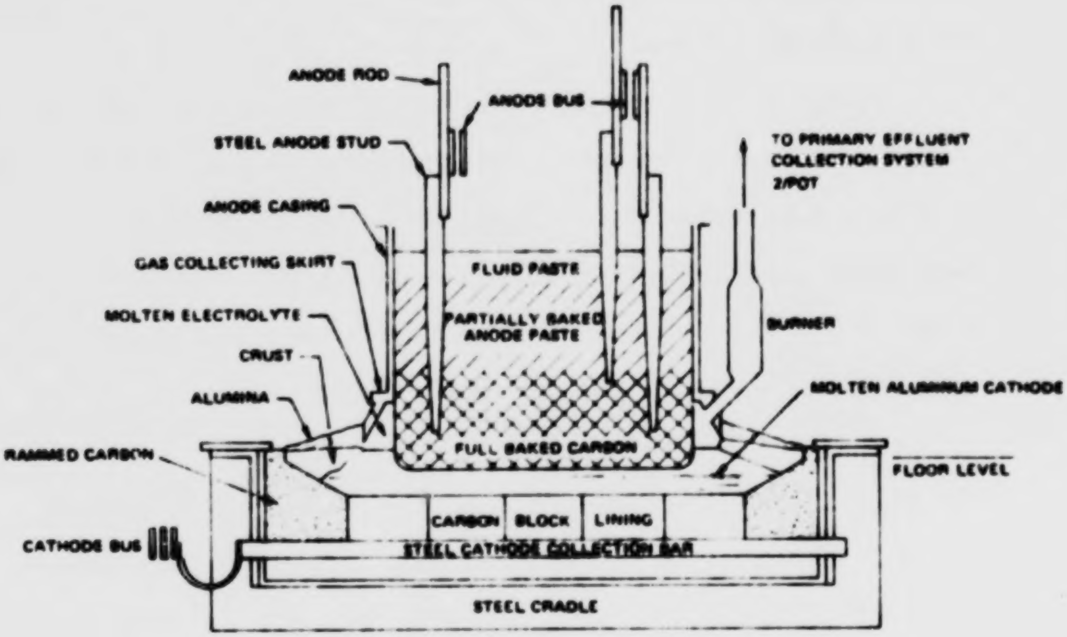
The Columbia Falls plant of the Anaconda Aluminum Company, with a design capacity of 180,000 tons of aluminum per year, has five pot lines consisting of 120 vertical stud Soderberg (VSS) pots or cells in each line. These five pot lines are contained in 10 large buildings approximately 1123 feet long, 87 feet wide, and 39 feet high. Each pot operates at a bath temperature of approximately 960°C and with a current of 107,000 amperes. Average power consumption at the plant is approximately 8,800,000 kilowatt-hours per day. In addition to the cell rooms, the plant includes an anode paste mixing process, an aluminum casting area, and an alumina receiving area.

The VSS type of cell is illustrated in Figure 2. Steel studs carrying the electrical current project vertically into the anode through the green or unbaked paste down into the baked portion of the anode. The cathode consists of the lower carbon cell lining with a steel bar embedded in it to carry the current. Long rows of cells connected electrically in series form a production "line".

The cell cavity contains the molten bath consisting of approximately 90 percent cryolite, 5 to 6 percent fluorspar, and 2 to 7 percent alumina. The molten bath is covered by a crust of frozen electrolyte and alumina. This crust diminishes heat loss from the top of the cell, reduces atmospheric emissions, and protects the carbon anode from oxidation. Periodically part of the crust is manually broken and stirred into the bath, and fresh alumina is added to form a new crust.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ANODE BUS
STEEL ANODE STUD
TO PRIMARY EFFLUENT COLLECTION SYSTEM 2/POT
ANODE CASING
GAS COLLECTING SKIRT
FLUID PASTE
MOLTEN ELECTROLYTE
PARTIALLY BAKED ANODE PASTE
BURNER
CRUST
ALUMINA
MOLTEN ALUMINUM CATHODE
FULL BAKED CARBON
RAMMED CARBON
FLOOR LEVEL
CARBON BLOCK LINING
CATHODE BUS
STEEL CATHODE COLLECTION BAR
STEEL CRADLE

Figure 2. Vertical-stud Soderberg aluminum manufacturing cell.

The electrical current decomposes the alumina in solution in the bath. Aluminum is deposited as molten metal on the bottom of the cell and the oxygen is liberated at the surface of the anode, where it reacts to form carbon oxides, which are released in the cell gases. The aluminum at the operating temperature of the cell is slightly more dense than the molten bath and forms a metal pad on the bottom of the cell.

As the anode carbon reacts with oxygen at the bath surface, additional anode material (green paste) is added manually to the top of the cell to replenish the anode.

Approximately once every 24 hours, molten aluminum is siphoned from the cell into an insulated steel container and is transferred to the cast house.

POLLUTANT EMISSIONS

Hydrocarbons, carbon monoxide, gaseous and particulate fluorides, and other particulate matter are emitted during the electrolytic reaction. Fluorides, both gaseous and particulate, and other particulate matter are the primary pollutants emitted from the cells. Total fluorides released from a cell amount to approximately 50 pounds per ton of aluminum produced, or about 44 pounds of fluoride per cell-day. Approximately 90 percent of this fluoride is reported to be in the gaseous form. Emissions of total particulate matter, including particulate fluorides, have not been reported, but are estimated to be about 100 pounds per ton of aluminum. An estimated 90 percent of the pollutants generated in a cell is captured by the primary cell ventilation system. Condensible organic matter (tar) escapes from the top of the anode. Additional fluoride pollutants and particulate matter escape to the atmosphere through breaks in the crust around the gas collecting skirt.

As shown in Figure 2, each cell is equipped with two vertical risers through which are exhausted 300 cfm of gases each to an air cleaning system. Atmospheric emissions from the bath that escape this primary control system are vented into the cell room and then out-of-doors through roof openings. Openings in the room walls and floor enable air to flow through the building.

Rates of air pollutant emissions from the Columbia Falls plant have varied during the life of the plant as new lines were brought into production and as control equipment was added or modified. Summaries of fluoride emissions from the plant since its startup in 1955 are given in Table 2 and Figure 3. A peak emission rate of approximately 7500 pounds of fluoride per day occurred during the interval 1968 to 1971. This peak resulted from the startup of new lines, associated operating problems, and the use of only a medium-efficiency scrubber on the primary control system. Starting in 1971, a more efficient primary control system was installed and is reported to have reduced total fluoride emissions from all the cells to 385 pounds per day. The emissions escaping into the room are reported also to have been reduced because of better operating practices and better fume control around each cell. The remaining emissions of 2200 pounds per day currently escape through roof monitors. Projected emissions shown for 1975 are those expected if a control system is installed to reduce emissions from the roof monitors. Total plant emissions at that time would be about 1235 pounds of fluoride per day, consisting of 385 pounds per day from the 30 primary systems and 850 pounds per day from the roof monitor controls.

Emissions of total particulate matter from the plant for the year 1972 are estimated to have been approximately 8000 pounds per day. Of this total, an estimated 500 pounds per day was discharged from the primary cell ventilation and scrubber systems, and the remaining 7500 pounds per day escaped through the roof monitors.

Gases and particulate matter captured by each primary

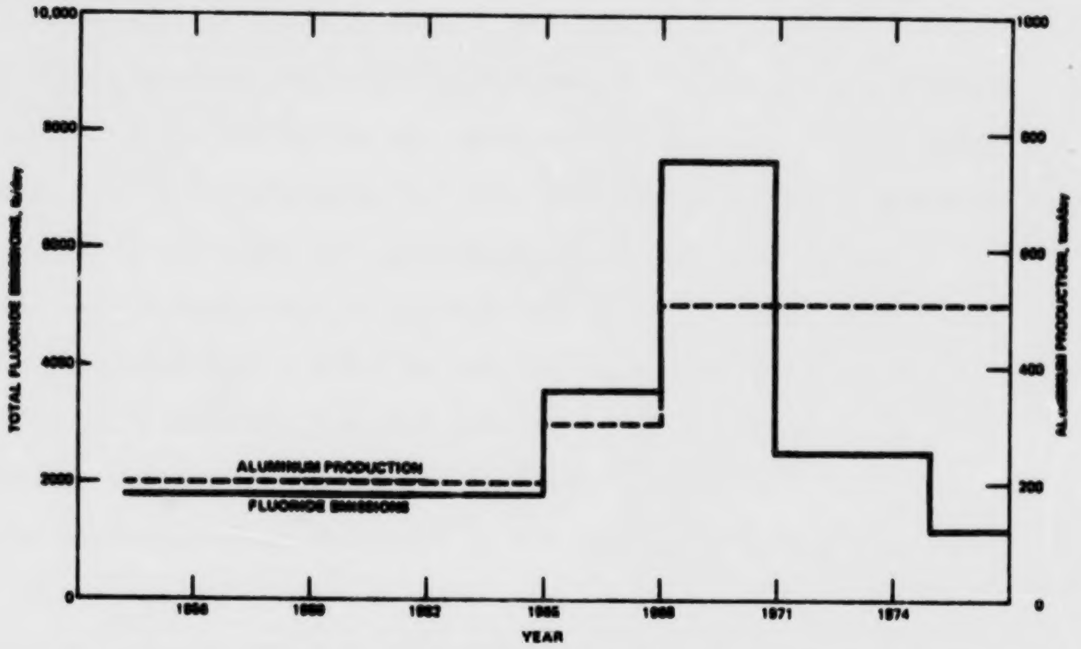


Figure 3. Estimated emission rates and aluminum production at Anaconda Plant in Columbia Falls, Montana.

cell ventilation system pass through an afterburner, a multicyclone, and a venturi scrubber followed in series by a packed bed (plastic saddles) scrubber. Each scrubber system serves 20 cells with a gas flow of 600 cfm per cell, yielding a total flow of 12,000 cfm per scrubber system. Each scrubbing system has a total pressure drop of 40 inches of water. Water is the scrubbing medium in the venturi unit and the packed bed scrubber. This water is treated with lime to control pH and remove fluorides. Scrubbing water is clarified and the overflow is recycled to the scrubbers. No waste water leaves the system. Wet sludge from the clarifier is removed periodically and

Table 2. ESTIMATED FLUORIDE EMISSIONS AND PROJECTED RATES FOR 1975

Years	Aluminum produced, tons/day	Number of pot lines	Total fluoride emissions		Primary controls	Control system emissions lb/day	Secondary controls	Emissions from roof, lb/day
			lb/day	lb/ton Al				
1955-1964	200	2	1900	9.5	Multiclone and wet scrubber	1200	None	700
1965-1967	300	3	3600	12.0	Multiclone and wet scrubber	1800	None	1800
1968-1970	500	5	7500	15.0	Multiclone and wet scrubber	3000	None	4500
1971-1974	500	5	2585	5.17	Venturi scrubbers	385	None	2200
1975-	500	5	1235	2.47	Venturi scrubbers	385	Roof scrubbers	850

disposed of on site. Dust collected in the multiclones is recycled to the electrolytic cells. The after burners incinerate carbon monoxide and hydrocarbons in the vent gas stream.

The total scrubbing system has an estimated efficiency of 98 to 99 percent in removing total fluorides.

Pollutants that escape from the cells and then through roof monitors during anode stud replacement and crust breaking, and from the green paste in the anodes are not now controlled at the Columbia Falls plant. A number of plants, including VSS type installations in this country and abroad, have installed low-pressure-drop water spray systems to treat emissions from roof monitors. These systems, which consist of a set of water sprays and a low-pressure-drop demister, can reduce emissions of particulate matter by possibly 50 percent and of gaseous fluorides by approximately 80 percent. Various configurations of this basic type of scrubbing system have been used. In one configuration spray and demister sections are contained in large ducts located adjacent to the plant building with connecting ductwork running to the inside of the roof. Roof strength and vent opening configurations largely determine the location of the scrubbing system.

METEOROLOGICAL STUDIES

A major factor in the identification and description of source-receptor relationships in air pollution problems is the movement of air in the geographic area of interest. For this study the EPA examined wind records applicable to the study area and also made surface wind measurements from mid-June until late December 1970 at three sites in the area.

In mountainous terrain, two air flow patterns, the upper level and the lower level winds, are of interest. The upper winds, as influenced by major geographic features, reflect the general motion of the atmosphere near mountaintop level. Low level wind patterns are influenced by interaction of upper winds with the localized mountain and valley winds.

Upper winds are monitored by the National Weather Service from a nationwide network of stations. The measurements are made with free-flight balloons normally released at midnight and noon Greenwich time. Upper wind stations nearest the study area are at Spokane, Washington, 200 miles to the west-southwest, and Great Falls, Montana, 80 miles to the east-southeast of the study area. Data on frequency of upper wind directions for the years 1961 through 1965 at these two stations are summarized in Table 3.

Table 3. FREQUENCIES OF OCCURRENCES OF WIND DIRECTIONS IN SUMMER MEASURED AT TWO NATIONAL WEATHER SERVICE UPPER AIR STATIONS NEAREST TO COLUMBIA FALLS, MONTANA, 1961 through 1965[a]

(Frequencies in percent)

Direction	Great Falls, Montana 2,000 m MSL		Spokane, Washington 1,500 m MSL	
	4 a.m.	4 p.m.	4 a.m.	4 p.m.
N	4.3	4.2	2.5	4.3
NNE	2.7	3.3	4.9	3.8
NE	2.7	4.9	3.8	4.5
ENE	4.0	5.4	7.4	3.2
E	4.5	4.7	3.6	2.7
ESE	3.4	5.1	2.9	0.2
SE	4.5	2.5	2.5	1.8
SSE	2.0	1.3	2.0	0.9
S	6.3	2.7	2.9	3.4
SSW	6.7	4.2	7.4	11.5
SW	7.2	7.6	26.8	28.4
WSW	16.1	14.5	15.4	18.3
W	19.7	19.0	8.7	8.4
WNW	8.9	7.8	4.3	2.9
NW	4.7	8.0	3.1	2.9
NNW	2.2	4.2	1.6	2.3
Calm	0.2	0.4	0.2	0.5

[a] From the available tabulations, the level closest to the flow over Columbia Falls and Teakettle Mountain is presented for each station. Values given are means over the 5-year period.

The upper winds appear to follow expected meteorological patterns for regions along the Continental Divide. The most frequent direction for Spokane is northwesterly, while that for Great Falls is westerly. The usual behavior of large-scale atmospheric motions when they encounter a mountain chain is for the winds on the downslope side to be directed to the right of the wind direction on the upslope side. This appears to be the case here, with westerly winds more frequent at Great Falls than at Spokane. In the absence of upper winds data obtained in the study area, one cannot be certain of wind behavior at and above ridge level. Available data, however, along with general knowledge on behavior of winds, suggest that the prevailing upper winds near ridge level in the study area should be generally southwesterly.

Surface wind data are recorded hourly at the Kalispell Airport, about 3 miles southwest of Columbia Falls, by the National Weather Service. A conventional wind rose derived from the airport data for the summer months over a 10-year period appears in Figure 4.

The airport data were supplemented by data obtained from three EPA wind recording stations whose locations are shown in Figure 5. Data obtained from these stations, as depicted in Figure 6, indicate marked differences among the stations, differences apparently caused by the typical mountain and valley local wind flow patterns. For example, Station 2 was located at the confluence of the North Fork and Middle Fork of the Flathead River. During nighttime and morning hours

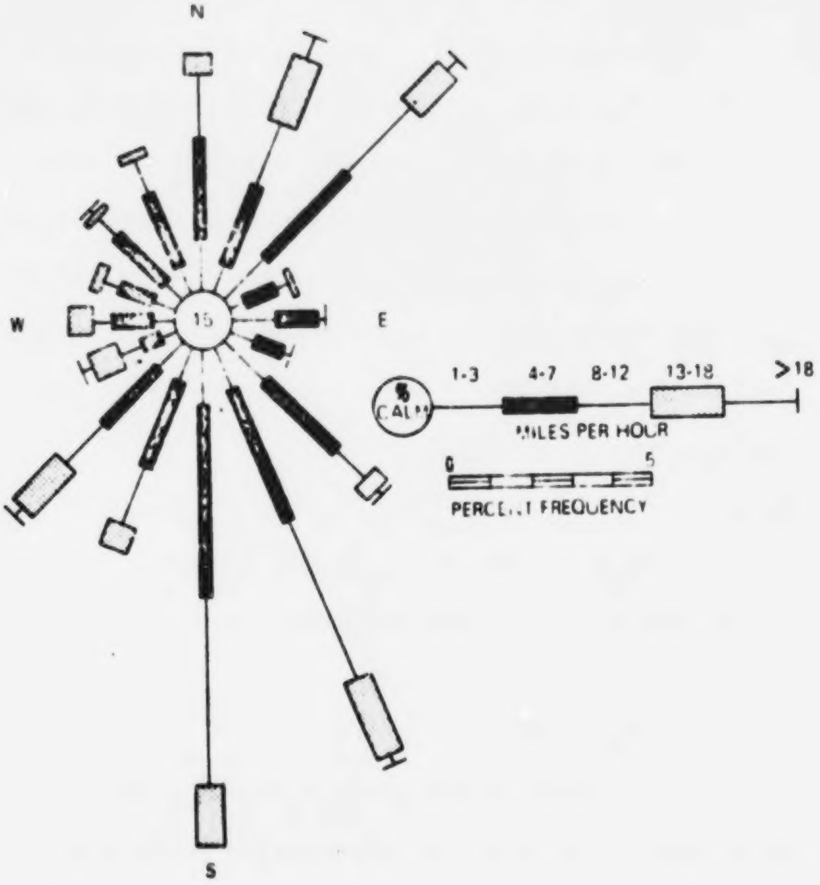
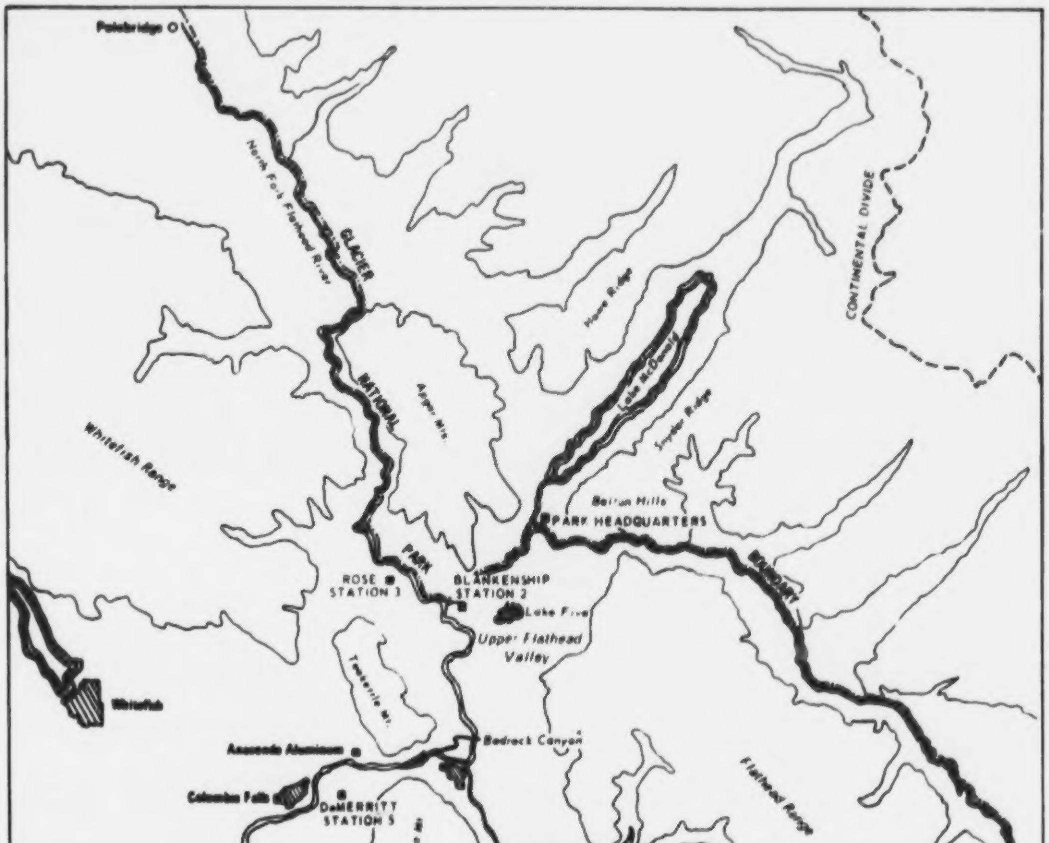


Figure 4. Wind rose for the months of June, July and August at Kalispell, Montana (1950 through 1959).[3]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Lake McDonald
Snyder Ridge
Apgar Mts.
Whitefish Range
Belton Hills
PARK HEADQUARTERS
ROSE
STATION 3
BLANKENSHIP
STATION 2
Lake Five
Upper Flathead
Valley
Teakettle Mt.
Whitefish
Bedrock Canyon
Anaconda Aluminum
Columbia Falls
DeMERRITT
STATION 5
Columbia Mt.
Flathead Range
Kalispell Airport
Lower Flathead
Valley
Flathead River
Hungry Horse Reservoir
Swan Range
Kalispell
Flathead Lake
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Figure 5. Location of meteorological observation stations.[3]

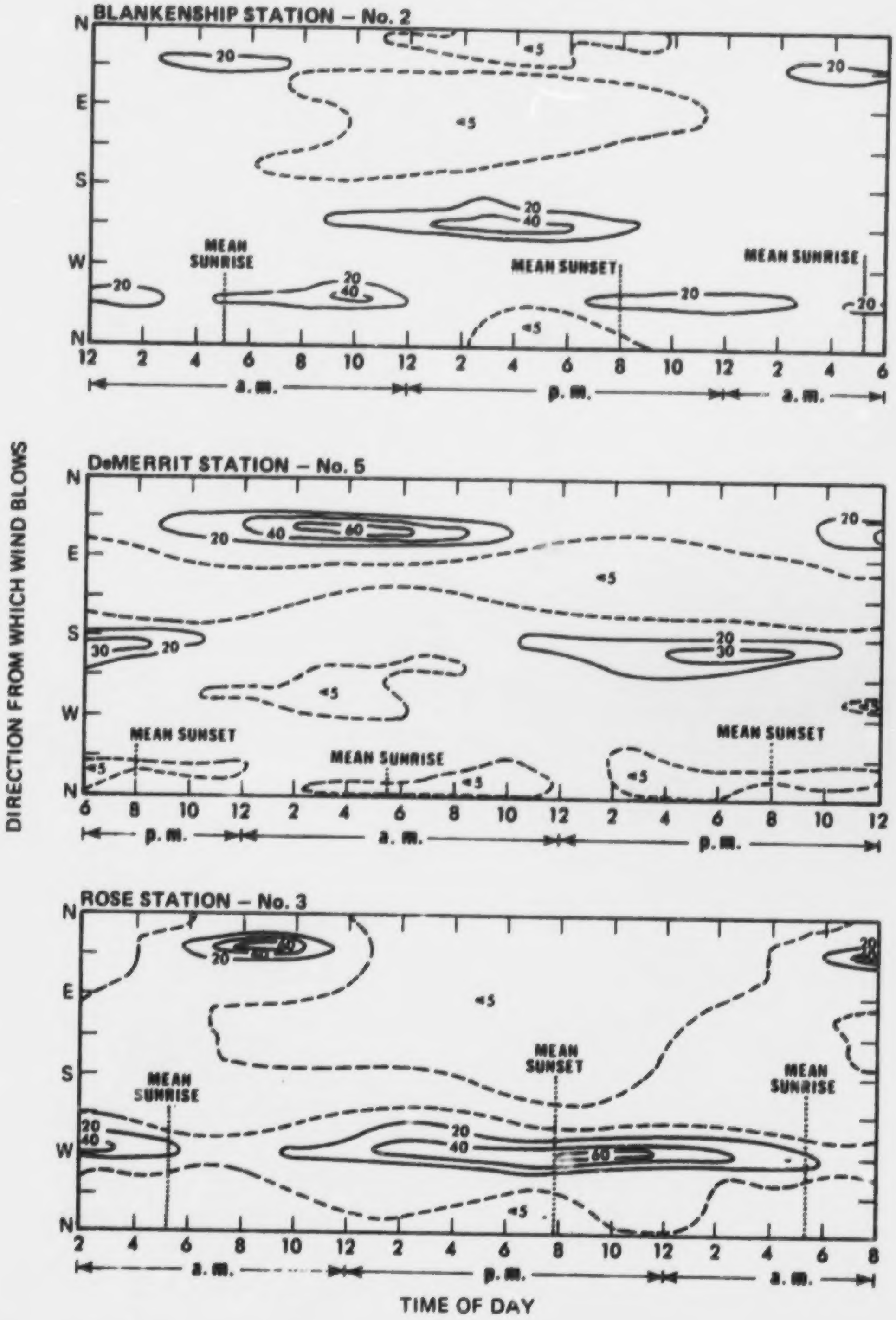

Figure 6. Dominant wind-flow patterns measured June through September 1970. Isolines show percent occurrence of wind direction at indicated times.[3]

downstream drainage flows alternate between the North Fork to the northwest (20 to 40 percent of the time) and the Middle Fork to the northeast (more than 20 percent of the time). During mid-day upslope winds from the southwest toward Lake McDonald predominate. At Station 5, nighttime drainage through Badrock Canyon between Teakettle and Columbia Mountains results in very dominant northeast winds. These winds persist until about mid-day before being reversed to upslope flow. The persistent west wind at Station 3 is largely attributed to daytime channeling when southerly or westerly winds in the lower basin of the Flathead River cause outflow around the north shoulder of Teakettle Mountain.

The lower Flathead Valley from Columbia Falls south to Flathead Lake is protected to a large extent from the upper winds by the mountains that surround it on three sides, leaving it relatively open only to the south. During nights when radiational cooling at ground level is effective, the air near the ground cools rapidly, becomes more dense, and begins to flow along the ground toward lower elevations. Effluents emitted from industrial operations are warm and rise until they are no longer buoyant, but remain below the crest of the confining mountains.

The air from the upper valley drains at night through Badrock Canyon and passes Station 5 as a northeasterly wind. This down-valley wind becomes apparent at about 10:00 p.m., reaches a maximum frequency of 67 percent near sunrise, and usually dissipates shortly after noon. The same air current is apparent at the airport, where it is more diffuse and northerly because of the inclusion of additional air currents as it spreads over the flat valley floor to Flathead Lake.

At sunrise the west sides of these two valleys with their east-facing slopes are warmed rapidly while the opposite valley walls, which remain in deep shadow, are cool. As vertical currents develop over sun-heated slopes, cooler replacement air from the down-valley flow is entrained and wind directions consequently shift. As direct sunshine progresses onto the broad lower valley floor, the related developing vertical currents progress upward into the blanket of stagnant air that accumulated during the night and mix the air downward to the surface as well as upward. Mixing continues to deepen until the currents reach mountaintop levels and the prevailing upper winds begin to entrain the valley air.

The shift of wind direction toward the slopes heated by the early morning sun is most striking at Station 3. Here a northeasterly wind appears to blow from the shaded side of the Apgar Mountains to the sunny side of Teakettle Mountain between the hours of 7:00 a.m. and 1:00 p.m., exceeding 60 percent frequency from about 8:00 to 10:00 a.m. During the morning, this flow of clean air into the upper valley shields the east face of Teakettle Mountain from effluents being carried aloft.

Up-valley wind flow develops and the mixing layer deepens until air from above the top of Teakettle Mountain is mixed with surface air throughout the upper valley during much of the afternoon. By this time, the nighttime stagnant air has already been carried away from the lower valley by the prevailing winds, and only current emissions are mixed through the deep layer of air to the surface in the upper valley so that the higher concentrations do not reach the floor of the upper valley.

The overall wind pattern when upper winds are from the southwest and the lower valley convection has broken through into the upper flow is shown pictorially in Figure 7. The viewer looks to the northeast across Teakettle Mountain and the Upper Flatland Valley to Lake McDonald. Direct sunshine has not penetrated the valleys in sufficient strength to reverse the down-valley winds along the river although upslope flow occurs on the sunny, east-facing slopes and the down-valley flow has turned somewhat toward these slopes. In the upper valley beyond Teakettle Mountain, the clean air flowing down along the rivers shields the surface from fluoride-laden air entrained in the upper level winds. This is the preponderant mid-morning wind pattern during the summer.

On days when southwest upper winds prevail, the highest concentrations of fluoride are carried into Glacier National Park in the forenoon. At sunrise the previous night's accumulation of effluents plus current emissions from the plant are being held within the lower valley and mixed in a deepening layer until this layer reaches and is entrained by the upper flow. The lower valley effluents are then carried in the upper flow over the upper valley and into the Park where they intercept terrain elements common to the height of the effluent

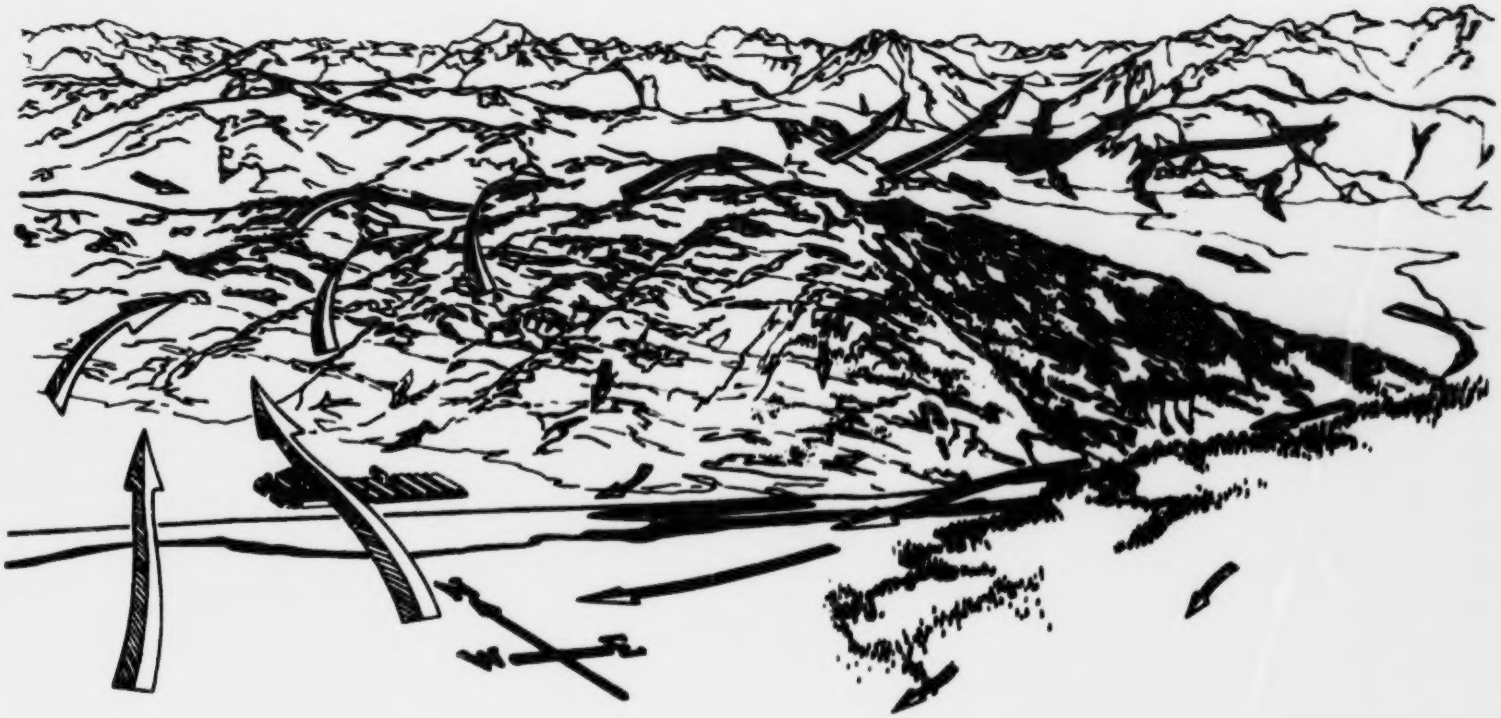

Figure 7. Simplified drawing of typical midmorning wind-flow patterns in upper Flathead Valley.[3]

An effort was made to estimate the relative seasonal impact of the aluminum plant on the Park. Dispersion calculations were performed assuming constant fluoride emission rate and diffusion parameters for the four seasons. Calculating on the basis of seasonal wind direction frequency, average wind speed, and duration of sunlight, the relative seasonal impacts are 100 for summer, 43 for fall, 38 for winter, and 54 for spring. These calculations, however, did not consider the impact of accumulated pollutants transported into the Park as a result of the local wind stability pattern discussed earlier. The conditions most conducive for development of this local pattern are generally light wind flow together with essentially cloudless skies. These conditions normally are most frequent in late summer through early fall. The analysis offered here suggests that the potential for damage within the Park is greater in summer through early fall than at other seasons of the year.

To learn whether weather conditions during the 1970 study period were similar to those of other years, EPA investigators compared records for 1970 at the Kalispell Airport with the means for that station over the past 30 years. This comparison indicates that the month of April 1970 in the study area was somewhat cool and dry with strong surface winds and the following 3 months were slightly warmer and wetter than normal. The fall months were somewhat cooler and drier than normal. Since these observed differences were not major deviations from the normal weather patterns, the 1970 data can be considered plume. As convective activity increases, more complete mixing occurs to higher levels of the atmosphere and dilutes the concentration of the remaining effluents.

With the increase in surface heating, the typical up-valley wind pattern develops in both the upper and the lower valleys and is augmented by a lake-to-land breeze from Flathead Lake.

Predominant southwest through west-southwest daytime winds above Teakettle Mountain apparently carry the effluents from the aluminum plant at Columbia Falls toward Glacier National Park. Frequencies of these transport winds, estimated from information available on upper winds, are given in Table 4.

Table 4. SOUTHWEST TO WEST-SOUTHWEST DAYTIME WINDS OVER TEAKETTLE MOUNTAIN[3]

Summer		Fall		Winter		Spring	
Frequency, %	Average speed, mph	Frequency, %	Average speed, mph	Frequency, %	Average speed, mph	Frequency, %	Average speed, mph
47	17	40	24	46	28	41	25

The highest frequency of wind direction that would carry effluents into the Park, and also the lowest average wind speed, occur in summer. Both factors would lead to relatively high fluoride levels at receptors in the down-wind direction. The long summer days average 15.2 hours between sunrise and sunset; thus, because the winds tend to blow toward the Park during daylight hours, emissions are carried into the Park over longer periods in summer than in other seasons.

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AMBIENT FLUORIDE CONCENTRATIONS

Measurements of fluorides in air in the study area were conducted by the EPA and cooperating agencies in the summer of 1970. Two types of air sampling were performed. One involves impaction of air on a chemically treated surface and yields a measure of fluoridation rate or "dosage", ordinarily recorded as weight of fluoride collected per unit surface area per unit time of exposure. The other involves a dynamic sampling method and yields values for the concentration of fluorides in air, reported as weight of fluoride per unit volume of air sampled. For convenience of reference, the first method is designated an "impact" method, and the second a "volumetric" method.

The impact measurements are made by exposing chemically treated filter paper to the air. The impact samplers are inexpensive and require no power source; they are thus readily placed at any accessible site and are useful in delineating spatial distributions of fluorides in a study area. Since the amount of fluoride taken up by the treated paper surface correlates reasonably well with the amount of fluoride that accumulates in vegetation with the same exposure, the fluoride dosage rate data yielded by this method are useful indicators of potential long-term or chronic fluoride damage to vegetation.

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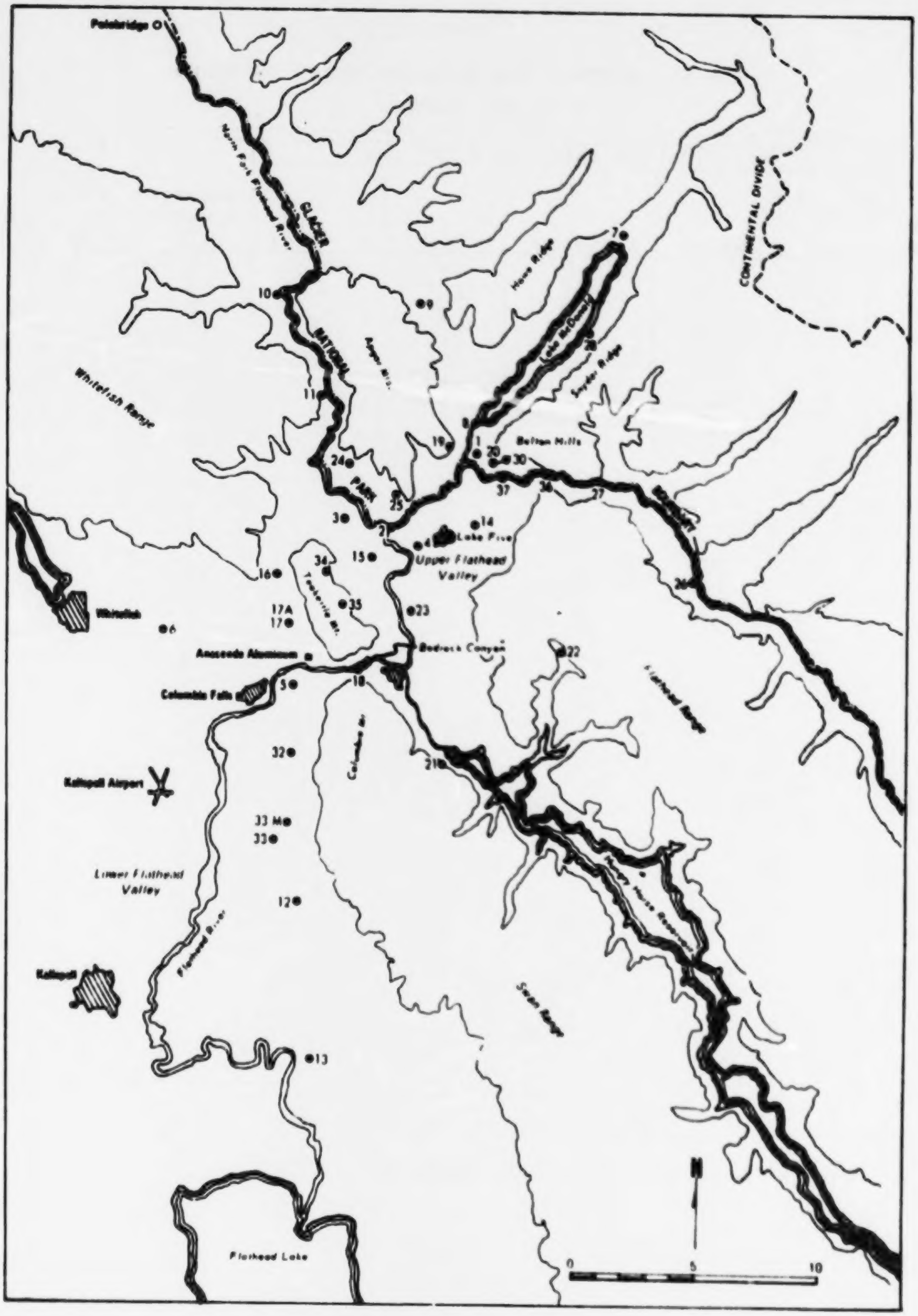
The volumetric measurements are made with sequential samplers that are capable of collecting gaseous and particulate fluorides separately. Since these samplers require electrical power, volumetric measurements in the study were limited to sites in the area where such power was available.

Impact measurements were made at 36 sites in the study area; site locations are shown in Figure 8. Fluoridation rates obtained for the months July through November at each sampling site, along with elevation of each site, are listed in Table 5. The geographic distribution of these rates is depicted in Figure 9. For this Figure the locations of isodose lines were estimated from the average monthly fluoridation rates obtained at the various sampling sites. A significant degree of judgement is involved in such construction because sampling data were not obtained for the entire area and because the mountainous terrain is uneven. Nevertheless, the values clearly decrease as distance from the aluminum reduction plant increases, except in the northeast quadrant where prevailing winds and higher ground elevations cause an elongation of the pattern in that direction. That higher fluoride dosage is related to higher ground elevation is indicated by comparing data from the two Teakettle Mountain sites (34 and 35) and from the Apgar Lookout site (19) with data from other sites nearby at lower elevation (1 and 8). Closed isodose lines appear on Teakettle Mountain and in the Apgar Lookout area of Glacier National Park, some 10 miles northeast and downwind from the plant.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Upper Flathead Valley
Teakettle Mt.
Whitefish
Anaconda Aluminum
Badrock Canyon
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Flathead Range
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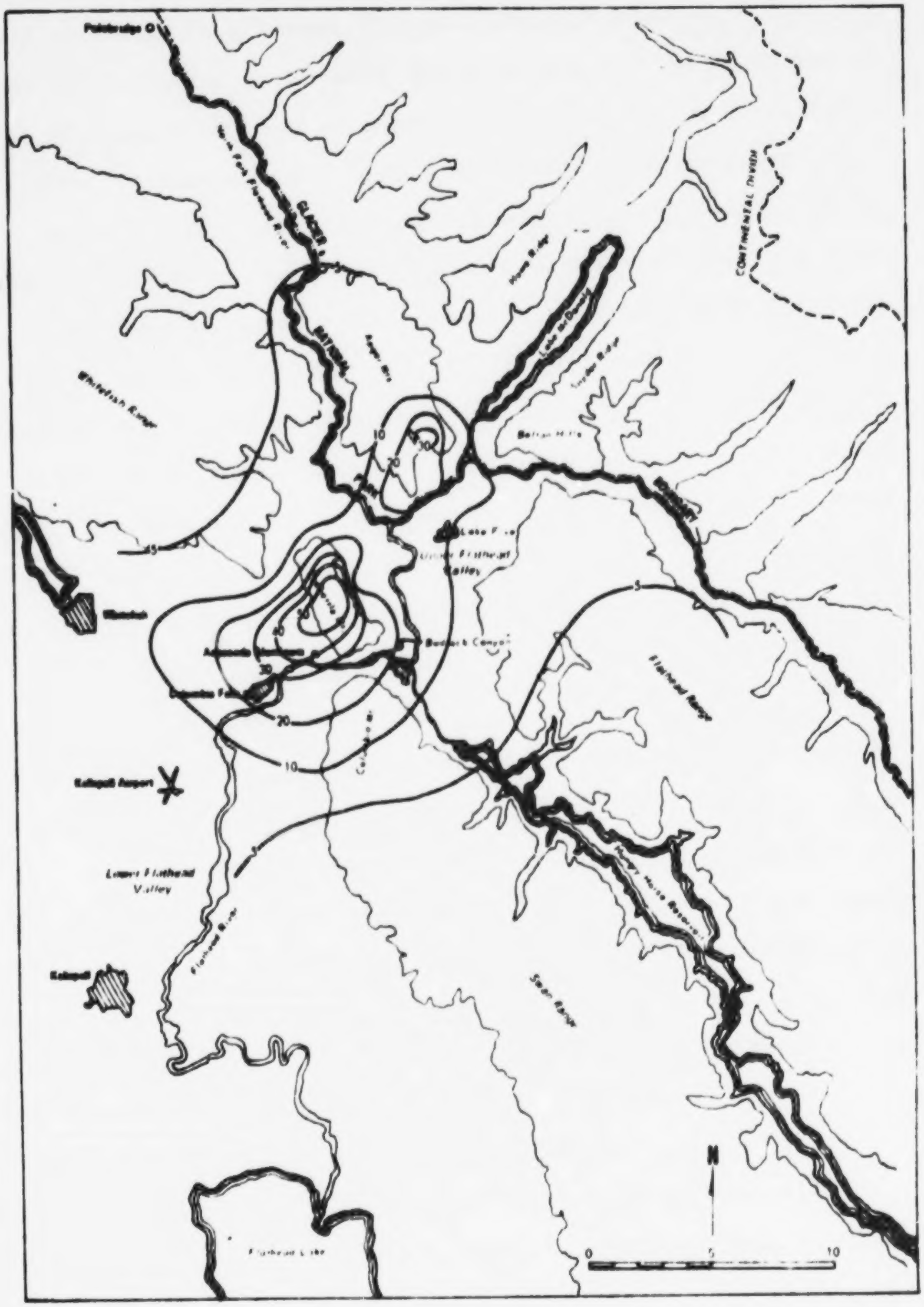
Figure 8. Location of fluoridation plate exposure sites.[3]

Table 5. MONTHLY FLUORIDATION RATES MEASURED WITH EPA PLATES[3]

Site number	Fluoridation rate, ng F/cm^2-day					Average monthly rate	Average Calcium Formate Equivalent, μg/cm^2-28 da.
	July	August	September	October	November		
1[a]	11[b]	13[b]	9[b]	10[b]	10[b]	11	0.19
2[a]	14[b]	13[b]	20[b]	11[b]	13[b]	14	0.25
3[a]	10[b]	10[b]	10[b]	4[b]	6[b]	8	0.14
4[a]	15[b]	23[b]	11[b]	12[b]	13[b]	15	0.26
5	29	30	32	16		27	0.48
6	15	10[b]	7[b]	4[b]		9	0.16
7[a]	14	9	8	7		10	0.18
8[a]	15	8	7	6	8	9	0.16
9[a]	10	5	4	4		6	0.11
10	9	5	4	2		5	0.09
11	9	8	3	2		6	0.11
12	7		3	2		4	0.07
13	10		4	4		6	0.11
14	13	12	9	5	6	9	0.16
15	17	19	14[b]	9[b]	10[b]	14	0.25
16	12	12	6[b]	5[b]		9	0.16
17	38	83[b]	43[b]	43[b]	23[b]	46	0.81
18	23	30[b]	21[b]	25[b]	37[b]	27	0.48
19[a]	20	29	48	22		30	0.53
20[a]	13	16	8	5	5	9	0.16
21	10	4[b]	5[b]	4[b]		6	0.11
22	8	5[b]	5[b]	3[b]		5	0.09
23	13	18[b]	13[b]	8[b]	16[b]	14	0.25
24[a]	9	8	5	3		6	0.11
25[a]	24	24[b]	26[b]	11[b]	18[b]	21	0.37
26	10	7[b]	6[b]	4[b]		7	0.12
27	6	7[b]	6[b]	4[b]	8[b]	6	0.11
28[a]	10	6	5	3		6	0.11
30[a]				8	8[b]	8	0.14
32		15[b]	9[b]	10		12	0.21
33		6[b]	5[b]	4[b]		5	0.09
33M		6[b]	5[b]	4[b]		5	0.09
34		37	41	91[b]		39	0.69
35			50[b]			71	1.25
36					9	9	0.16
37[a]					9	9	0.16

a) Exposure sites located in or near Glacier Park.

b) Value is average of two or more duplicate readings.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Badrock Canyon
Columbia Falls
Flathead Range
Kalispell Airport
Lower Flathead Valley
Flathead River
Kalispell
Hungry Horse Reservoir
Swan Range
Flathead Lake
N
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5
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40
50

Figure 9. Distribution of average monthly fluoridation rates.[3]
(Isoline values in ng F/cm^2-day)

As previously stated, fluoride impact data were not obtained to cover the entire study area. One can extrapolate, however, from information developed on the channeling of winds and from data that show higher fluoride pollution at higher elevations on Teakettle Mountain and Apgar Lookout than at nearby lower elevations; these data suggest some departures from the distribution pattern shown in Figure 9. It may reasonably be supposed that the upper elevations of the Belton Hills and adjacent mountains and peaks in the Flathead Range, the Whitefish Range, and the Swan Range, which comprise the Flathead National Forest area are exposed to higher fluoride levels than are nearby sampling sites at lower elevations. Data on the geographic distribution of fluoride content of sampled vegetation support this supposition.

The Montana ambient air quality standard for fluoridation rate (0.30 $\mu gF/cm^2$-28 days) is based upon a specified measurement technique involving exposure of calcium-formate-impregnated paper in a louvered shelter. The EPA method uses filter paper discs impregnated with sodium formate, mounted with one side exposed in small dish-shaped plates and exposed face downward. Eighteen simultaneous exposures of the calcium formate and the sodium formate devices at selected study area sites over monthly intervals from July through December yielded fluoridation rates for calcium formate papers which average 0.68 the rate for sodium formate plates. The final column of Table 5 lists the average monthly fluoridation rate for the sodium formate plates adjusted by the factor 0.68, and for a

28-day interval, for comparison with the Montana standard. The average rate exceeded the State standard at 7 of the 36 exposure sites over the period of measurement. The fluoridation rate measured by the EPA method equivalent to the Montana standard is 17 ngF/cm^2-day. Of the 140 site-months of measurement, the rates for 29 exceed this index. Further, one may conclude that the geographic area depicted within the 20 ngF/cm^2 day isoconcentration lines of Figure 9 was subjected to average fluoride contamination in excess of the State standard over the study period.

Volumetric measurements of gaseous and particulate fluoride concentrations were made at three locations in the study area from June 26 to October 23, 1970 (Stations 1, 2, and 4). These monitoring stations were located at sites ranging from 7 to 11 miles northeast of the aluminum plant, as shown in Figure 10. Availability of electrical power was one determining factor in locating the stations. A fourth sampler was operated at Station 3 from June 26 through August 11, then was moved to Station 17, the Dehlbom residence about 1.5 miles north of the aluminum plant, where it was operated from August 17 to October 21.

Sequential samplers capable of separating gaseous and particulate fluorides were used for these measurements. Air entered a sampler through a bicarbonate-coated glass tube, which selectively absorbed gaseous fluorides. After removal of the gaseous fluoride component, particulate fluorides were collected on a chemically treated filter mounted at the outlet

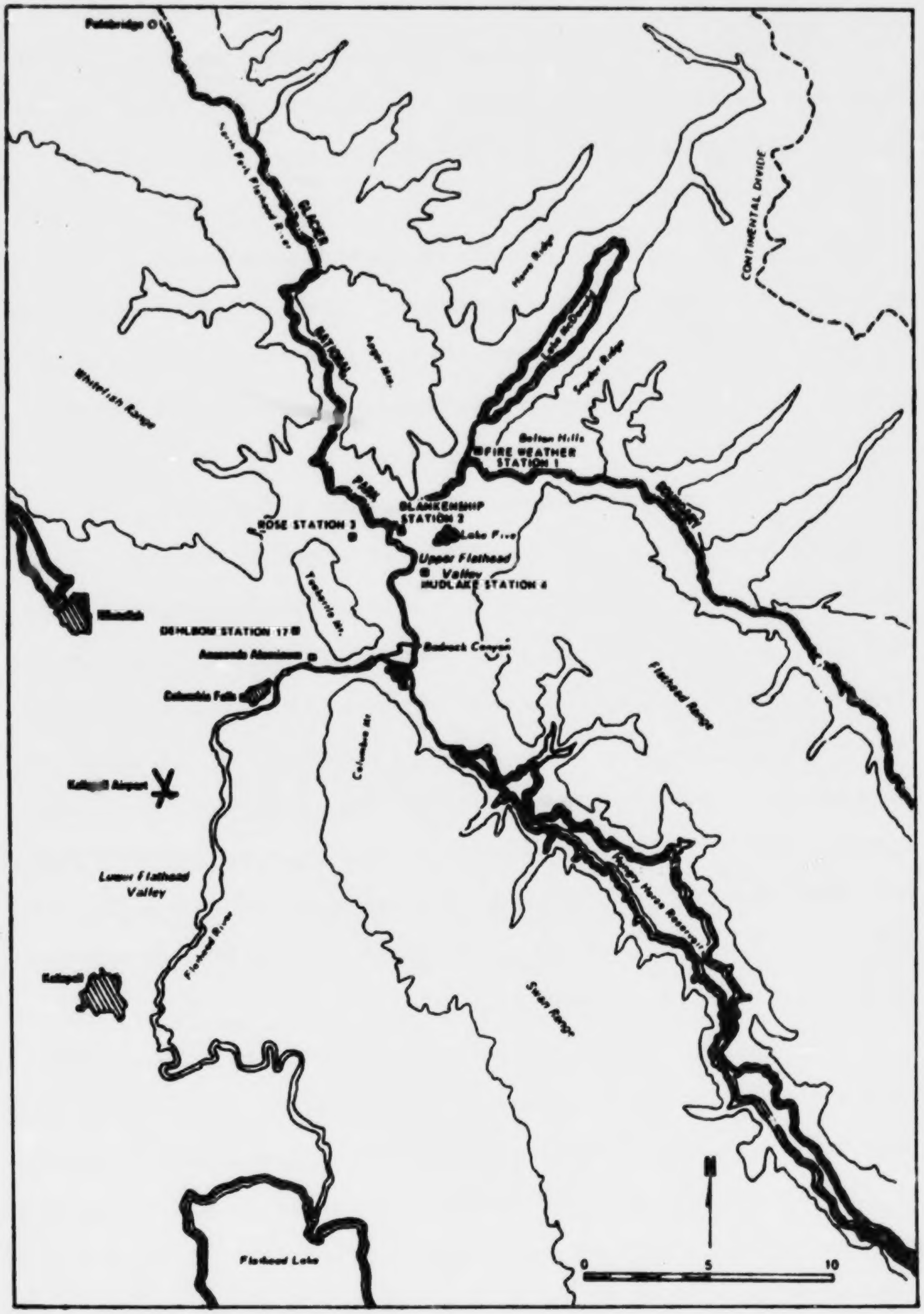
Polebridge
North Fork Flathead River
GLACIER
NATIONAL
PARK
Apgar Mt.
Howe Ridge
Lake McDonald
Snyder Ridge
CONTINENTAL DIVIDE
Whitefish Range
Belton Hills
FIRE WEATHER
STATION 1
BLANKENSHIP
STATION 2
ROSE STATION 3
Lake Five
Upper Flathead
Valley
MUDLAKE STATION 4
Teakettle Mt.
Whitefish
DEHLBOM STATION 17
Bad Rock Canyon
Anaconda Aluminum
Columbia Falls
Flathead Range
Columbia Mt
Kalispell Airport
Lower Flathead
Valley
Flathead River
Hungry Horse Reservoir
Kalispell
Swan Range
N
Flathead Lake
0
5
10

Figure 10. Location of volumetric fluoride monitoring stations and plant exposure shelters.[3]

end of the tube in each sampler. Glass tubes and filters were analyzed for fluoride in an EPA laboratory. Fluorides retained in the tubes and on the filters were determined by the specific fluoride electrode method.[5]

An interval control timer built into the sampler enabled continuous collection of samples over 12-hour intervals from 9:00 a.m. to 9:00 p.m. (daytime), and 9:00 p.m. to 9:00 a.m. (nighttime). Samples adequate for analysis were obtained about 70 percent of the time that the samplers were operated.

The 24-hour period beginning with the daytime sampling interval, which starts at 1:00 a.m., is taken to represent a calendar day. Average and maximum concentrations of gaseous and particulate fluorides measured during daytime and nighttime intervals and averaged for calendar days at the five sampling sites are summarized in Table 6. The values for individual samples are presented elsewhere.[3]

The Montana State standard limits the concentration of gaseous fluoride over a 24-hour period to 0.8 $\mu gF/m^3$. This value was exceeded at the Dehlbom site on three successive days during the period of sampling. The standard was not exceeded for any of the arbitrarily defined calendar days at any of the other four sites, but was exceeded for a 24-hour period from 9:00 p.m. September 5 to 9:00 p.m. September 6 at Station 2, the Blankenship Station, where a mean value of 0.83 $\mu gF/m^3$ was measured for that time interval.

On the average, gaseous fluorides represent approximately one-third of the combined concentrations of gaseous and parti-

Table 6. SUMMARY OF 12-HOUR GASEOUS AND PARTICULATE FLUORIDE CONCENTRATIONS MEASURED IN GLACIER NATIONAL PARK AND SURROUNDING AREA, JUNE 26 to OCTOBER 23, 1970

($\mu g\ F/m^3$)

Station	Fluoride component	Daytime		Nighttime		24-hour[a]	
		Maximum	Average	Maximum	Average	Maximum	Average
1	Gaseous	0.34	0.09	0.25	0.05	0.25	0.07
	particulate	0.84	0.18	1.18	0.13	0.91	0.15
2	Gaseous	0.65	0.12	1.02	0.07	0.66	0.10
	particulate	0.73	0.22	0.98	0.12	0.64	0.17
3	Gaseous	0.16	0.06	0.12	0.06	0.14	0.06
	particulate	0.51	0.12	0.32	0.11	0.36	0.12
4	Gaseous	0.48	0.14	0.20	0.06	0.28	0.10
	particulate	1.12	0.27	1.33	0.17	0.84	0.21
17[b]	Gaseous	3.65	0.48	1.05	0.18	2.11	0.33
	particulate	2.70	0.79	2.41	0.55	1.57	0.65

[a] Average of daytime and nighttime values.

[b] Special sampling station operated from August 17 to October 21, 1971 at Dehlbom residence about 1.5 miles north of the aluminum plant.

culate fluorides measured. In situations of high gaseous fluoride concentration, however, such as those wherein the State standard was exceeded, gaseous fluoride concentrations approached or exceeded the particulate fluoride concentrations. At all but one sampling site (Station 3), daytime gaseous fluoride levels averaged about twice the nighttime concentrations. Differences in airflow patterns during daytime and nighttime are thought to account for the higher daytime concentrations. It is noted, too, that gaseous fluoride data generally showed a trend toward lower values as the study progressed. Several explanations of this trend are possible: (1) daylight hours were reduced 25 percent from summer to fall, (2) aluminum production may have been reduced, (3) more efficient fluoride emission controls were installed at the plant, and (4) a combination of the above or other factors.

The mean ratio of results from monthly sodium formate plate impact sampling to those from gaseous fluoride volumetric sampling for the five stations where companion sampling was done indicates that 1 ngF/cm^2-day was equivalent to about 0.006 μgF/m^3. This suggests that the area within the 10 ngF/cm^2-day isoline of Figure 9 was subjected to an average gaseous fluoride concentration of about 0.06 μgF/m^3 over the entire 4-or 5-month period of impact sampling.

VEGETATION STUDIES

Phytotoxicity of airborne gaseous fluoride is well documented in the literature. Several reports relate specifically to investigations in areas near aluminum reduction plants. Foliar necrosis and retarded diameter growth in Ponderosa pine near the Kaiser Aluminum Company aluminum reduction plant at Mead, Washington, was reported; injury could not be attributed to insects, fungi, or climate, but was highly correlated with foliar fluoride concentrations.[6] In another study a nearly sixfold decrease in diameter growth rate in Ponderosa pine near the same reduction plant, attributed to fluoride, was reported.[7] Findings of foliar necrosis attributed to elevated fluoride levels and not to fungal, climatic, or insect agents were reported for a study done in the vicinity of the Harvey Aluminum Company reduction plant at The Dalles, Oregon.[8] Ponderosa pine has been specifically studied as an indicator of fluoride pollution, and was found to exhibit foliar necrosis with fluoride insult.[9]

Fluoride is an accumulative toxicant, and development of plant injury is usually associated with fluoride buildup in the leaf over a relatively long period of time in contrast to short-time exposure that normally causes injury with atmos-

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pheric phytotoxicants. Also, the fluoride ion is relatively stable in contrast to the structure of many pollutants that break down or change chemically within a leaf. Leaves on the same plant can differ considerably in fluoride content because leaves differ in age or exposure time.

Fluorides enter needles and leaves mainly through stomata. Once in the foliar tissue, they are soluble, free-flowing, and tend to accumulate at conifer needle tips or broadleaf margins, causing tip or margin necrosis. Because particulate fluorides are readily adsorbed to dust particles, dust on the leaf surface may aid in accumulating fluorides.[10]

A wide variation in sensitivity is recognized; some species of plants may accumulate more than 100 parts per million (ppm) of fluoride on a dry weight basis without displaying symptoms of injury, whereas other species may develop extensive areas of dead tissue when much less fluoride has been accumulated. It is generally accepted that fluoride concentrations in plants up to 10 ppm may be considered normal occurrence and that some plants, particularly those closely related to tea, may accumulate much larger amounts in the absence of atmospheric contaminants. In a plant community such as that found in Flathead County, concentrations exceeding 10 ppm in grasses and pine needles are probably associated with atmospheric contamination.

The aluminum reduction plant at Columbia Falls began operation in 1955. By 1957 Ponderosa pine trees in the vicinity of the plant were dying. After inspecting the trees a

Forest Service pathologist reported by memorandum his opinion that the injury was caused by fluorides emitted from the reduction plant. In the summer of 1969 an EPA botanist investigated vegetation in the Columbia Falls area for possible damage from fluoride. Tip damage and leaf margin burn characteristic of injury by fluoride were found in pine, apple, and willow trees and in gladiolus. Chemical analysis of leaf specimens from these species demonstrated fluoride accumulation (pine, 70 ppm; apple, 150-190 ppm; willow, 70-210 ppm; gladiolus, 90-170 ppm).[3] In further evaluations later in 1969, Forest Service officials found tissue necrosis and elevated fluoride levels in 26 of 35 vegetation samples representing Ponderosa pine, lodgepole pine, western white pine, and Douglas fir from the vicinity of the aluminum plant.

FOREST SERVICE STUDIES

The comprehensive studies initiated in 1970 included systematic evaluation of vegetation injury by fluorides in Flathead County. The Forest Service adopted a radial sampling system. Ten radii were established extending from the aluminum plant into adjacent forested lands, as illustrated in Figure 9. On each radius, basic plots one-hundredth acre in size (6.6 feet wide by 66 feet long, oriented longitudinally) were established at distances one-fourth, one-half, one, two, four, six, and eight miles from the plant. Additional plots were established at 10, 12, and 14 miles on radii 4 and 5, and at 14 miles on radius 6 to sample vegetation in Glacier National Park.

In the Forest Service studies two areas were selected for control sampling, one 30 miles south of Columbia Falls near Big Fork, Montana, and the other about 15 miles west of Kalispell. The locations were upwind of the aluminum plant in terms of the general prevailing southwesterly winds. Three plots, each one-hundredth acre in size, were established in each area. All conifer and shrub species on the plots were sampled, and also representative herbaceous plants and at least one grass species.

Control and radial plots were sampled twice in the 1970 Forest Service studies, once during June-July and again in October-November. The June-July collection is identified as the "first sampling" and the October-November collection the "second sampling". Separate foliage samples from one or more conifer species, one representative each of two shrub species, and one representative of each of one herbaceous and one grass species were collected from each plot. Foliage collected from each grass, broadleaf plant, and deciduous conifer was considered a separate sample. Foliage collected from other conifers was separated by year of origin, and foliage of each year was considered a separate sample. Generally only 1969 and 1970 needles were collected.

In addition to sampling within the systematic radial design, the Forest Service collected a supplemental series of special samples in areas deemed most likely to sustain high fluoride exposures. Because fluorides are transported in the atmosphere, vegetation on ridges and prominent topography downwind from the aluminum plant may be more likely to intercept fluorides than is vegetation in valleys or other more protected areas. Special sampling was conducted in the following locations: (1) near Columbia Falls, (2) Columbia Mountain, (3) Teakettle Mountain, (4) Southwest Glacier National Park, (5) Coram Experimental Forest near Desert Mountain, and (6) northeast edge of Hungry Horse Reservoir. Samples were not collected on a plot basis as described for the systematic radial collections; rather, vegetation representative of the area, with emphasis on coniferous species, was collected in June and October 1970.

In the Forest Service studies needles of each conifer sample were sorted by year of origin, 1969 or 1970, and the proportion showing foliar burn on visual examination was recorded. The average length of burn on affected needles was estimated as well. For shrub foliage, the proportion of leaves showing burn was recorded and the fraction of area affected was estimated. Subsamples of conifer needles, shrub foliage, grass, and herbaceous tissue were sent to the Wisconsin Alumni Research Foundation Institute, Inc., Madison, Wisconsin, (WARF) for fluoride analysis by a specified method.[11] Histological analysis of conifer specimens was done in Forest Service laboratories.

EPA STUDIES

In the EPA investigations of 1970, indigenous vegetation was examined for visible foliar damage, and foliage specimens were obtained for chemical analysis for fluoride and for histological examination. In addition, studies were made with selected vegetation species grown under controlled conditions in plant shelters located at various places in the study area. Field examinations for visible injury were made in the vicinity of Columbia Falls and to the south toward Flathead Lake, on the north and south slopes and the top of Teakettle Mountain, and at various sites in Glacier National Park.

Plant shelters that permit exposures limited to ambient air for a known interval of time without influence of local soils were operated from June 25 to October 21, 1970, at stations 1, 2, and 3. Station locations are identified in Figure 10; companion control shelters were operated at stations 1 and 2. The plant shelters, which were small cylinder-shaped fiberglass greenhouses, were equipped with exhaust fans that drew ambient air through the units at a rate of about one air change per minute. Control shelters were identical to the exposure shelters except that they were equipped with an inlet blower and filters to remove particulate and gaseous fluorides from the incoming air.

Plants exposed in the shelters included Ponderosa pine, Scotch pine, white pine, Chinese apricot, Snow Princess gladiolas, and alfalfa. All trees were obtained from outside the study area; the Ponderosa pines from Potomac Valley, Missoula, Montana; the Scotch pines from St. Regis, Montana; the white pines from Coeur d'Alene, Idaho; and the Chinese apricots from Denver, Colorado. The pines were 3 to 4 years old, and the apricot trees were 5 to 6 years old; all trees were kept in the soil in which they were delivered by the nursery.

Gladiolus and alfalfa were grown hydroponically in a vermiculite support medium. Plastic pots containing the plants were placed in shallow plastic trays to which a deionized water nutrient solution was added twice a week. On a weekly schedule, all plants were flushed with distilled water, and the trays were cleaned to rid them of algae. In the latter stages of the study, heaters were placed inside the shelters to prevent freezing.

The selected plant varieties were also grown in garden plots near the shelters at sites 1, 2, and 3. An additional garden plot was established at the air sampling station near Mud Lake at Site 4. Gladiolus and alfalfa were planted in native soil at each of the garden plots, but the trees were left in their containers with the original soil. The garden plots were watered about every other day with deionized water and once a week with nutrient solution.

ESL STUDIES

A most extensive sampling of vegetation was conducted in the study area by the Environmental Studies Laboratory (ESL) of the University of Montana. Vegetation samples for fluoride analysis were collected in the 1970 studies from 19 sampling zones encompassing an area of more than 400 square miles. Zone boundaries were established on the basis of fluoride content of coniferous foliage from initial collections made in June and early July 1970. Although the zones vary in size, the concentrations of fluoride in samples in the initial collections within a zone were fairly similar. Zone boundaries are shown on the study area map of Figure 11. Each zone was given the name of a prominent feature such as a mountain, lake, or town within its boundaries; names and approximate sizes of zones are as follows:

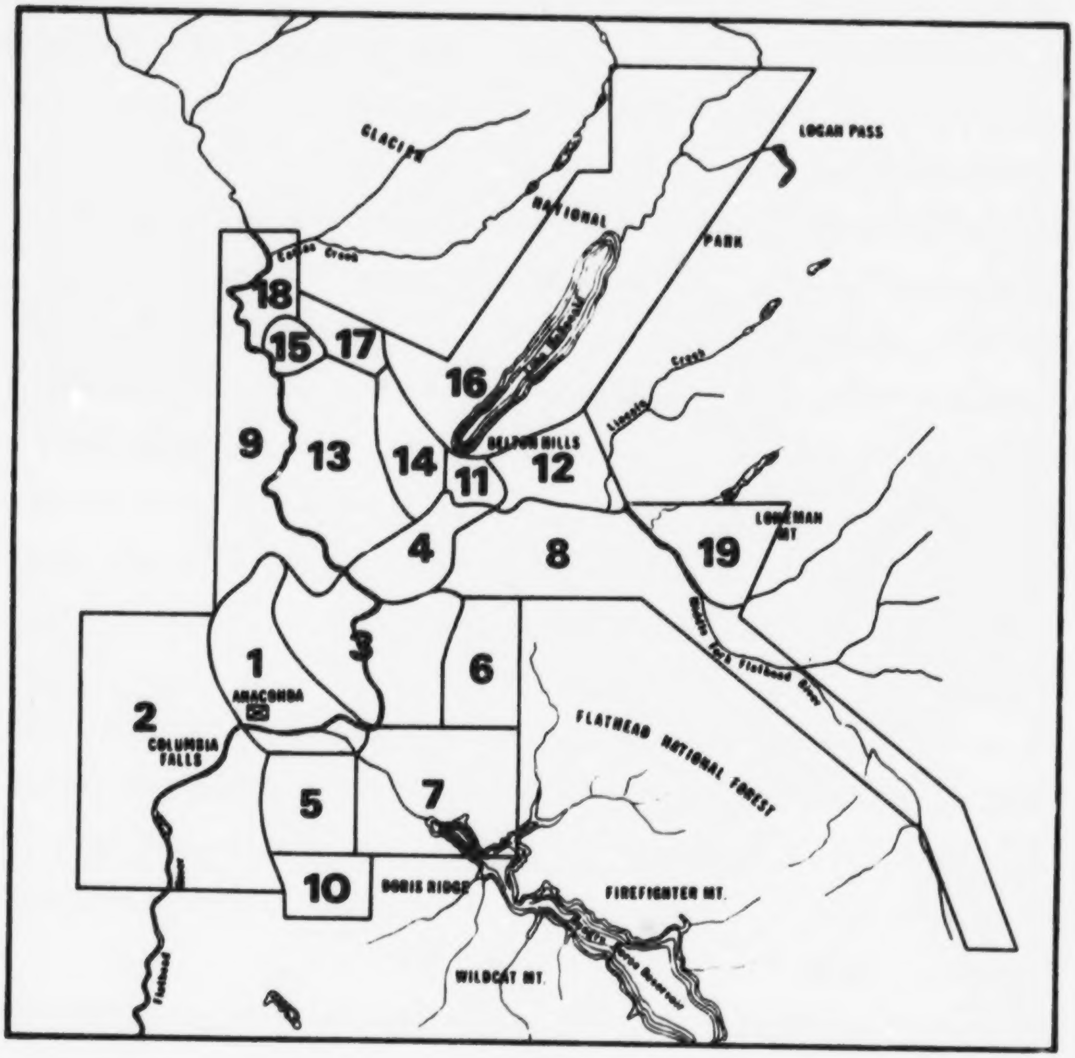
GLACIER
NATIONAL
PARK
LOGAN PASS
18
15
17
16
9
13
14
11
BELTON HILLS
12
Lincoln
Creek
LONEMAN MT
4
8
19
Middle Fork Flathead River
1
ANACONDA
3
6
2
COLUMBIA FALLS
FLATHEAD NATIONAL FOREST
5
7
10
DORIS RIDGE
FIREFIGHTER MT.
WILDCAT MT.
Flathead

Figure 11. Map of study area and location of sampling zones.[4]

1. West Face of Teakettle Mountain - 12,670 acres
2. Columbia Falls - 36,860 acres
3. Coram - 11,520 acres
4. Lake Five - 9,220 acres
5. Columbia Mountain - 5,890 acres
6. Desert Mountain - 7,680 acres
7. South Fork (of the Flathead River) - 18,180 acres
8. Middle Fork " " " " - 26,880 acres
9. North Fork " " " " - 17,410 acres
10. Doris Mountain - 4,100 acres
11. Headquarters Hill - 2,880 acres
12. Belton Hills - 9,360 acres
13. Apgar Ridge and Middle Fork Ranger Station (MFRS) - 12,800 acres
14. Apgar Lookout - 3,330 acres
15. Boehm's Bear Den - 2,880 acres
16. Lake McDonald - 57,860 acres
17. Camas Creek - 8,960 acres
18. Huckleberry Mountain - 6,400 acres
19. Loneman Mountain - 7,680 acres

Sampling stations numbered 11 through 19 are located in Glacier National Park, and those numbered 1 through 10 are outside the Park.

For controls, vegetation samples were obtained from locations in Montana 40 to 150 miles distant from Columbia Falls. These control areas included:

Elk Creek

Many Glacier

St. Regis
Rogers Pass
Upper St. Mary's Lake
Swiftcurrent
Twin Creek
Swan Valley

Most vegetation samples collected in the ESL studies were coniferous foliage. These accounted for some 1600 fluoride analyses in the 1970 studies alone. In addition to foliage, pollen from some coniferous species was collected and analyzed for fluoride. Stems and terminal buds from both coniferous and hardwood species were also collected and analyzed, as was grass from all but one of the sampling zones and from a number of control locations.

With the exception of larch, coniferous trees growing in the Flathead County area of Montana generally retain three years of needle growth. Thus, it was possible to collect needles from the years 1968, 1969, and 1970 from most of the trees sampled. A sample of conifer foliage having 3 years of growth yields more information than vegetation samples from deciduous trees and shrubs, which lose their leaves each year. For example, a conifer sample with 3 years' growth collected early July 1970 can indicate how much fluoride has accumulated in the 1970 foliage during the few weeks it has been exposed, how much has accumulated in the 1969 needles in 13 or 14 months of exposure, and how much in 1968 needles over a period of 25 or 26 months.

All fluoride analyses of vegetation samples in the ESL studies were done by the Orion ion specific electrode method; some duplicate analyses were done with the Autotechnicon semiautomated method.[4] As previously mentioned, the fluoride analyses for samples obtained in the 1970 Forest Service studies were performed by WARF. Portions of each of 10 conferous foliage samples collected by ESL were analyzed separately by ESL and WARF. Results of these analyses appear in Table 7. For the values in Table 7 the least squares relationship is:

$$C_b = 0.87\ C_a - 0.67$$

and the coefficient of linear correlation is 0.89. The mean value of the ratio of WARF to ESL results is 0.79. Results of this experiment suggest that WARF results are fairly consistently 20 to 25 percent higher than those of the ESL.

VISIBLE INJURY

Observation of indigenous vegetation by an EPA botanist in 1970 revealed visible injury in the form of needle tip necrosis on various species of pines in the study area.[3] Such damage, primarily to 1968 needles, was identified in and around Columbia Falls, nearby Lake Five, at the eastern base of Apgar Mountain, at Glacier National Park Headquarters, and at the Lake McDonald Ranger Station. It was found as far distant from the aluminum reduction plant as 10 miles southeast of Columbia Falls along the Columbia Falls-Bigfork highway, and 6 miles north of the north shore of Lake McDonald in Glacier National Park. Severe needle necrosis was seen on pines on the south slope and at the top of Teakettle Mountain, where many young trees were severely defoliated, or partially or entirely dead; damage observed on the north slope was less severe.

Table 7. FLUORIDE CONCENTRATION IN TEN CONIFEROUS FOLIAGE SAMPLES ANALYZED INDEPENDENTLY BY WARF[a] AND BY ESL[b]

(ppm by weight)

Sample	WARF	ESL
1	87.0	74.0
2	35.5	30.0
3	24.0	28.0
4	11.8	5.1
5	10.5	7.2
6	10.4	8.4
7	10.3	11.0
8	8.5	6.4
9	8.5	3.2
10	3.5	3.3

[a] Wisconsin Alumni Research Foundation Institute

[b] Environmental Studies Laboratory, University of Montana

Foliage specimens obtained in the systematic radial plot sampling program conducted by the Forest Service were examined for visible damage. Needles from each conifer sample were sorted by year of origin; the fraction showing visible injury was determined for each year sub-sample, and for this damaged fraction the average fraction of needle length of burn was estimated. The product of the fraction of needles showing injury and the average fraction of needle length of this injury was identified as the Injury Index (I.I.). The results of this systematic assessment of visible injury are tabulated in Appendix A. In its classification of visible injury, the Forest Service identifies light injury as an I.I. greater than 0.006 and severe injury as an I.I. greater than 0.10. In the first sampling of radial plots in 1970, light injury was identified at distances as great as 4 to 8 miles northwest, north, and southeast of the aluminum plant, and 14 miles toward the northeast. Injury Indexes greater than the severe damage level were determined for samples from radial plots 2 miles north and northeast of the plant, and generally 4 miles northeast. One plot located in the Belton Hills of Glacier National Park, 12 miles northeast of the plant, yielded an I.I. showing severe damage.

HISTOLOGICAL RESPONSE

Solberg and Adams[12] and Gordon[13] in controlled studies described histological responses of conifers to fumigations by fluorides. Protoplasmic and nuclear hypertrophy of parenchyma cells resulting in death of foliar phloem tissue were regarded as symptomatic of fluorosis in conifer tissue. The

Environmental Studies Laboratory of the University of Montana obtained burnt or necrotic needles from pine species at 40 different sites in the study area. More than half of these sites were in Glacier National Park at distances greater than 6 to 10 miles from the reduction plant. Histological study of every needle collection selected showed the specific disease syndrome that is manifested by conifer needle tissues damaged by atmospheric fluorides. At the time of selection, information on fluoride content of the needles was not available. Subsequent analysis of selected specimens exhibiting the fluoride-caused disease syndrome gave the following results for each of the three major species of pine:

a. Ponderosa pine, 1969 needles, Apgar Ridge and MFRS zone, 27 ppm fluoride.

b. Lodgepole pine, 1969 needles, Headquarters Hill zone, 17.5 ppm fluoride.

c. White pine, 1969 needles, Belton Hills zone, 12.5 ppm fluoride.

These sampling zones are located at successively greater distances from about 6 to about 12 miles northeast of the aluminum plant. The analysis were made on whole needles, not just the necrotic tip; the results demonstrate that tissue necrosis is associated with whole-needle fluoride concentrations only a few times greater than those found in normal healthy needles. (Control samples of conifer foliage in ESL studies yielded fluoride concentrations averaging about 2 ppm, with a maximum value slightly over 5 ppm.)

Histological examination of necrotic conifer needles (9 micra thick sections) in the Forest Service studies is described as follows:[1]

> "Microscopic examination of conifer tissue in the early stage of necrosis (green-yellow part of transition zone) revealed that phloem and transfusion parenchyma and albuminous cells hypertrophied extensively, crushing and causing collapse of transfusion tracheids and phloem elements.... Enlarged nuclei were always associated with the hypertrophied cells.... Often the mesophyll cell immediately interior to the stomatal opening had been killed before fixation and sectioning. Epithelial tissue and nuclei hypertrophied extensively, often occluding resin canals....
>
> "In the later stage of fluorosis (necrotic portion of transition zone), many of the hypertrophied cells had collapsed, leaving a void in the tissue. Granulosis of the chloroplasts in mesophyll cells was obvious.
>
> "This disease syndrome is unlike any caused by fungi or adverse weather conditions, and is very distinctive for fluorosis of conifer tissue."

In its histological studies of conifer needle specimens from the study area, the EPA took sections from the green portion of the needles immediately preceding the demarcation line between injured and uninjured tissue. Microscopic examination revealed that the parenchymatous tissues of palisade and spongy cells were collapsed and some chloroplasts had lost their integrity. The epithelial cells of the resin canal showed swelling and expansion. The vascular bundles were distorted, and adjacent cells had collapsed. The EPA, too, concluded that the causative agent of the needle necrosis was chemical rather than biological or meteorological.

FLUORIDE CONTENT

Of all the vegetation work undertaken in the study program, that which most effectively demonstrates levels of fluoride pollution in the study area involved measurement of fluoride content of foliage from indigenous plants. During 1970 the Forest Service collected for fluoride analysis 1254 vegetation samples from its radial plots, 175 such samples from special sampling sites, and more than 100 from control sites. Summaries of the Forest Service data resulting from analysis by WARF appear in Appendix A. The 1970 studies of the Environmental Studies Laboratory, University of Montana, involved some 1600 fluoride analyses of coniferous foliage, and about 600 additional analyses of conifer and hardwood stems, conifer pollen, and grass. Summaries of the ESL vegetation data appear in Appendix B.

Values for fluoride content of vegetation collected in the Forest Service radial sampling system were averaged on a plot-by-plot basis irrespective of vegetation type. This procedure is considered valid for comparison of plots because nearly the same amounts and types of vegetation were collected from all plots. For every radius in the Forest Service sampling analysis indicates a trend of very high fluoride content in samples taken near the aluminum plant, with concentrations decreasing to near control levels at the most distant plots. The tables of Appendix A show the same general trend for separate types of vegetation as for the averages over entire plots.

Figure 12 shows the geographic distribution of average fluoride concentrations in vegetation as indicated by the

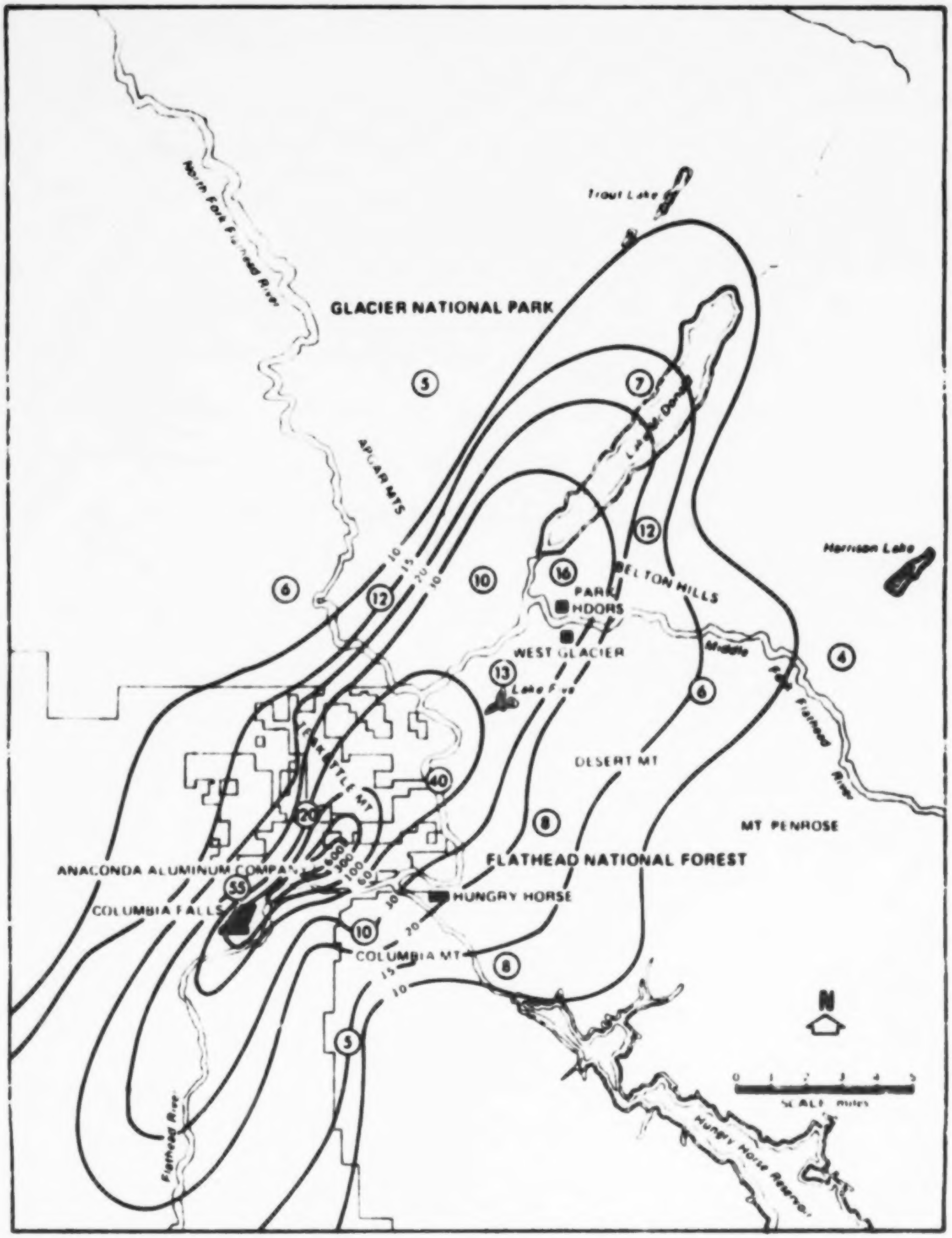
North Fork Flathead River
Trout Lake
GLACIER NATIONAL PARK
5
7
APGAR MTS
12
Harrison Lake
6
12
10
15
20
30
10
16
BELTON HILLS
PARK HDQRS
WEST GLACIER
Middle Fork Flathead River
4
13
Lake Five
6
DESERT MT
40
20
8
MT PENROSE
FLATHEAD NATIONAL FOREST
ANACONDA ALUMINUM COMPANY
600
300
100
60
55
30
HUNGRY HORSE
COLUMBIA FALLS
10
20
COLUMBIA MT
8
15
10
N
5
0 1 2 3 4 5
SCALE miles
Hungry Horse Reservoir
Flathead River

Figure 12. Isopols of fluoride pollution in vegetation from Forest Service data, 1970.[1] Circled numbers are sampling zone means of fluoride content of coniferous foliage, ESL data, 1970.[4] All concentration values ppm by weight.

Forest Service studies, depicted in the form of isopols, or lines of equal fluoride concentration in vegetation. From graphs of fluoride concentration versus distance from the aluminum plant for all the radial profiles (second sampling), the distance at which average fluoride concentrations equalled the arbitrarily selected levels of 10, 15, 20, 30, 60, 100, 300, and 600 ppm were estimated. Those distances along the radii were plotted on a map of the study area, and points of equal pollution (fluoride concentration) levels were connected by lines. Data from the first sampling gave a similar pattern, as did data for the separate categories of vegetation. The distribution of fluorides generally corresponds with the prevailing southwesterly winds, and the shapes of the isopleths are similar to those for fluoridation rates as depicted in Figure 9. The total area within each isopol, i.e. the total area sustaining fluoride levels equal to or greater than the given isopol value, and the incremental areas between adjacent isopols are tabulated in Appendix A. Vegetation on approximately 214,000 acres had accumulated more than 10 ppm fluoride, on about 69,000 acres had accumulated 30 ppm or more, and on more than 7,000 acres had accumulated 100 ppm or more The isopols for the area southwest of Columbia Falls were constructed from special sample data and may not be as reliable as those estimated from radial-plot data. They are, however, indicative of the general pattern in a southwesterly direction. Much vegetation in the area within the 30-ppm isopol has been affected to various degrees by fluorides from the aluminum plant.

As stated earlier, the sampling zones for the ESL studies were selected on the basis of fluoride concentrations in vegetation samples taken in the initial sampling of 1970; each zone represents an area having fairly consistent values of fluoride concentration among the various samples. A summary of results of fluoride analyses of conifer foliage samples obtained by ESL in its 1970 studies appears in Appendix B. The mean fluoride concentrations of conifer foliage samples, irrespective of species, collected in the 19 ESL sampling zones are given in Table 8. Sampling zones numbered 11 and higher are inside Glacier National Park, those numbered 10 and lower are outside the Park. As with the Forest Service data, the concentrations of fluoride in vegetation as determined in the ESL studies decrease with increasing distance from the aluminum reduction plant, and the concentration pattern is elongated in the northeasterly direction from the plant. This pattern is consistent with the prevailing southwesterly winds. The mean fluoride concentrations (ppm) in 1969 conifer needles collected by ESL are shown in Figure 12 in circles placed in the general locations of the sampling zones and superimposed on the isoconcentration lines yielded by the Forest Service studies. When one considers that the ESL and the Forest Service samples were collected at different times and places and that species included in the samples are distributed differently, the agreement in concentration values

Table 8. MEAN CONCENTRATION OF FLUORIDE IN CONIFER NEEDLES AND GRASS, ESL SAMPLES

(ppm by weight)

Sampling Zone		Conifer Needles Year of Origin			Grass 1970
No.	Name	1968	1969	1970	
1	Teakettle Mountain	244	120	18.6	87.4
2	Columbia Falls	102	54.8	28.9	149.1
3	Coram	73.6	39.7	7.6	14.7
4	Lake Five	24.3	13.0	4.8	5.4
5	Columbia Mountain	16.8	9.6	5.0	14.0
6	Desert Mountain	15.9	7.9	3.8	5.6
7	South Fork	13.7	8.1	3.6	7.1
8	Middle Fork	11.4	5.9	3.5	4.0
9	North Fork	10.5	6.0	4.6	6.3
10	Doris Mountain	7.6	4.5	3.3	3.8
11	Headquarters Hill	30.2	15.9	4.9	7.7
12	Belton Hills	27.0	12.4	4.8	10.2
13	Apgar Ridge and MFRS	26.3	12.0	4.7	7.8
14	Apgar Lookout	19.0	9.8	4.8	4.8
15	Boehm's Bear Den	12.5	7.2	4.0	2.8
16	Lake McDonald	12.2	7.1	4.0	10.4
17	Camas Creek	7.9	4.8	3.1	5.1
18	Huckleberry Mountain	7.0	4.7	3.5	-
19	Loneman Mountain	6.0	4.3	2.4	4.6
	Controls	2.2	2.4	2.0	4.4

is extraordinarily good.

A summary of data on fluoride concentrations in grass obtained by the ESL in its 1970 studies appears in Appendix B. Mean values for fluoride concentration by ESL sampling zone are given in the final column of Table 8. About half of these mean values are near values for control grass samples; 40 percent of the mean values range from about 2 to more than 30 times greater than control values. The two highest values, as would be expected, are for samples nearest the aluminum plant. These results are not unlike those yielded by grass samples from the Forest Service radial plot system. Of the some 70 plots from which grass samples were obtained, about 60 percent yielded fluoride concentrations ranging from 2 to 50 times greater than the mean for control samples. In comparing results of the ESL and Forest Service studies, however, one must keep in mind that some 30 of the Forest Service plots, including most of those within 2 miles of the aluminum plant, lie within Zone 1 of the ESL study. The mean fluoride concentration in grass from ESL zone 1 and the mean for Forest Service plots within that Zone are both about 20 times greater than control values. Of grass samples from the remaining ESL zones and Forest Service plots, between 35 and 40 percent showed mean fluoride concentrations in the range of 2 to 25 or 30 times greater than control values.

The ESL studies included innovative investigations into fluoride content of plant tissues other than conifer needles and grass. Samples of conifer stems for fluoride analysis were collected in the late fall and winter of 1970 after seasonal rains and snowfall had occurred in the study area. Results of the analyses are presented in Table 9. For the 15 samples from three southwestern zones of Glacier National Park the difference between average fluoride concentrations in coniferous stems that were washed and average concentrations in and on coniferous stems left unwashed was 1.2 ppm of fluoride. This slight difference indicates that very little or no particulate fluoride, such as aluminum fluoride, cryolite, or sodium fluoride, was being retained on conifers growing in Glacier National Park. Similar analyses of washed and unwashed conifer stems from control areas yielded an average difference in fluoride concentration of about 0.5 ppm. Slight differences between concentrations in washed and unwashed stems of control vegetation may be attributed to soil particles containing fluoride being blown by winds and lodging on the rough bark surface of conifer stems. Such particles are expected to be dislodged by the agitation and washing procedures and to account for the 0.5 ppm difference in fluoride readings.

The difference between fluoride concentrations of washed and unwashed stems from Columbia Falls, Zone 2, suggests that some particulate fluoride does accumulate on the surface of stems in locations near the aluminum plant.

In every case, stem samples from the study area yielded higher fluoride concentration values than did control samples. In samples from the Glacier National Park zones the values

Table 9. FLUORIDE CONCENTRATIONS IN WASHED AND UNWASHED CONIFER STEMS[4]

Sampling zone	No. samples	Fluorides, ppm by weight					
		1968 Stems		1969 Stems		1970 Stems	
		washed	Un-washed	washed	Un-washed	washed	Un-washed
Columbia Falls Zone 2	12	8.0	13.0	9.3	14.2	11.0	14.0
Coram, Zone 3	8	6.3	7.0	6.0	7.7	7.2	8.5
Glacier Park Zones 11, 12, 13	15	5.2	6.5	5.8	7.1	6.0	7.0
Controls	11	3.7	4.1	4.0	4.6	4.0	4.6

were not remarkably higher than the controls, but in those from the Columbia Falls zone the values exceeded control values by factors of 2 to 3. The data demonstrate that fluoride is being retained in and on the various years' stem growth, and that the concentrations tend to decrease slightly each year. This yearly decrease may result from leaching caused by exposure to weather or from the increase in the volume of older tissues, or both.

Because bark cannot be removed from coniferous stems without removing large portions of the active tissue of the inner stem, separate analyses of the outer bark and of the inner bark and cambial tissues of conifers were not undertaken. Because such separation is possible in hardwoods, samples of various hardwood species were obtained and separate analyses were performed on these tissues. Table 10 shows the average fluoride concentrations of washed and unwashed tissues from the stems of three species of hardwoods collected from selected ESL sampling zones of the study area and from control areas. Results are presented for three different series of stem tissues.

1. Bark and cortex
2. Phloem, cambium, and outer xylem
3. Core (xylem and pith).

Results of the fluoride analyses of unwashed bark demonstrate that high concentrations of fluoride particulate were present on hardwood stems obtained on the West Face of Teakettle Mountain. Concentrations of fluoride particulate on unwashed hardwood stems were lower in samples from the Columbia

Table 10. FLUORIDE CONCENTRATIONS IN WASHED AND UNWASHED TISSUES FROM 1970 HARDWOOD STEMS[4]

(ppm by weight)

Sampling zone	Bark and cortex		Phloem, cambium, outer xylem		Xylem and pith	
	HCl washed	un-washed	HCL washed	un-washed	HCl washed	un-washed
Teakettle Mountain Zone 1	8.5	44.0	7.2	8.4	2.8	3.6
Columbia Falls Zone 2	7.9	25.3	6.8	7.1	3.2	3.1
Coram Zone 3	7.5	8.2	6.2	6.5	3.1	2.8
Glacier Park Zones 11, 12, 13	6.4	8.5	5.8	8.5	2.9	3.2
Controls	3.2	4.6	2.9	4.6	3.0	2.6

Falls zone 4 1/2 miles west of the plant, and much lower in samples from the Coram zone 6 1/2 miles to the east. Very little fluoride particulate was found on hardwood stems from the Glacier National Park zones; concentrations were comparable to those found on coniferous stems.

The average fluoride concentrations found in the washed bark and cortex were similar in hardwood samples collected from the Teakettle Mountain, Columbia Falls, and Coram zones (8.5 to 7.5 ppm). The average fluoride concentrations in washed samples from the Glacier National Park zones were slightly lower, but still were twice as high as the average in washed samples from the control areas.

Fluoride concentrations in the inner active tissues of hardwoods (phloem, cambium, and outer xylem) from the study area were about 2 times greater than concentrations in similar inner-stem tissues of hardwoods from control areas. Average fluoride concentrations in the core tissues (xylem and pith) of stems of all samples taken from the study area and from the control areas were similar and quite low (2.6 to 3.6 ppm).

Samples of conifer pollen collected from control areas and from 14 of the 19 ESL sampling zones were analyzed for fluoride content. Results of pollen analyses are summarized in Table 11.

The mean fluoride concentration for seven pollen samples from control areas is 3.8 ppm. The mean fluoride concentrations in pollen samples from 9 of the 14 study area zones sampled are greater than the mean value for control samples by a factor of

Table 11. FLUORIDE CONCENTRATIONS IN CONIFEROUS POLLEN[4]

Sampling zone	No. samples	Fluoride, ppm by weight		
		Mean	Maximum	Minimum
1. Teakettle Mountain	4	23.2	32.0	13.7
3. Coram	8	12.0	16.0	8.0
4. Lake Five	3	15.6	19.8	11.0
5. Columbia Mountain	2	6.2	7.3	5.1
6. Desert Mountain	1	19.5		
8. Middle Fork	8	5.6	8.0	1.7
9. North Fork	3	8.1	9.2	6.4
11. Headquarters Hill	6	14.3	18.0	10.0
12. Belton Hills	1	13.3		
13. Apgar Ridge and MFRS	3	12.0	17.8	6.1
15. Boehm's Bear Den	3	5.6	8.4	3.0
16. Lake McDonald	4	7.8	10.0	6.0
17. Camas Creek	2	4.8	5.7	3.8
18. Huckleberry Mountain	2	4.2	6.6	1.9
Controls	7	3.8	5.5	1.7

2 or more.

Sampling zones 1, 4, 5, and 6, which gave relatively high values of fluoride in pollen, are generally near the aluminum plant. Zones 11, 12, and 13, also with high values, are located at distances of 6 to 10 miles from the plant. Because pollen is not directly exposed to ambient air during microsporogenesis within the staminate cone, one may reason that fluoride probably comes to the pollen via leaf tissues. For the same reason, one may suspect that the fluoride content is unlikely to be greatly affected by direct deposition of particulate fluoride. This latter supposition is supported by the relatively high values for fluoride in pollen from Zones 11, 12, and 13, zones for which data on washed and unwashed conifer stems indicate that fluoride content is not surface particulate.

In two separate visits to the study area, in July and October 1970, EPA investigators obtained samples of foliage from indigenous conifers. Needles of these samples were separated by year of origin and cut in approximate halves representing tip and base; the sub-samples were analyzed separately for fluoride content. Results of these analyses appear in Table 12. Samples obtained 4 miles southwest of Glacier National Park Headquarters and at the Middle Fork Ranger Station yielded fluoride concentrations somewhat higher than those obtained in larger samplings by the Forest Service and ESL in the same general areas. Otherwise, the results of these samplings are consistent with results of the more extensive samplings, show-

Table 12. FLUORIDE CONCENTRATION IN INDIGENOUS CONIFER FOLIAGE, EPA SAMPLING, 1970[3]

(ppm by weight)

Location and Species	Year of Origin							
	1967		1968		1969		1970	
	Tip	Base	Tip	Base	Tip	Base	Tip	Base
Teakettle Mountain								
Lodgepole Pine			328	37	260	46	34	
Ponderosa Pine			295	101	213	56		
Site 4, Mud Lake[a]								
Lodgepole Pine			72		61	14	15	11
Ponderosa Pine					122	9	39	11
4 miles Southwest Park Headquarters								
Ponderosa Pine	83	8	68	5	50	9	10	4
Middle Fork Ranger Station								
Douglas Fir			141	32	74	16	20	5
4 miles West Park Headquarters								
Lodgepole Pine			63		15			
Glacier Park Headquarters								
White Pine	30	12	36	13	28	8	8	5
6 miles North Lake McDonald								
White Pine			19	8	54	18		

[a] Samples taken 10/22/70; all others taken 7/16/70.

ing the trend of decreasing fluoride concentrations with increasing distance downwind from the aluminum plant. Separate analyses of tip and base show marked differences in levels of fluoride accumulation in these two portions of needles, results consistent with findings of tip necrosis.

Foliage from plant specimens grown in EPA controlled-exposure chambers and in special garden plots for varying intervals of time during summer 1970 were analyzed for fluoride content. Results of these analyses are presented in Tables 13 through 16. In nearly every case, fluoride concentrations in foliage from plants grown in the ambient air of chambers or in garden plots were greater than those in foliage of comparable plants grown in the cleaned air of the control chambers. Concentrations in exposed plants generally were 2 to 3 times greater than in control plants. These differences are attributed to atmospheric fluorides rather than to fluorides in soil or rainfall. They represent exposures for only a portion of the year; air quality data for that season at the same exposure sites demonstrate that the plants encountered relatively low atmospheric concentrations of fluorides.

In the course of their studies, the ESL investigators considered the matter of fluorides in soils. They collected and analyzed samples of soils from 11 of the 19 sampling zones and from one control area. Results of these fluoride analyses are presented in Table 17. The sample from the control area, Mac Donald Pass, yielded a fluoride concentration of 250 ppm, higher than, or similar to,concentrations in samples from 9 of the 11

Table 13. FLUORIDE ACCUMULATION IN 1969 AND 1970 NEEDLES OF WHITE, PONDEROSA, AND SCOTCH PINES EXPOSED FROM JUNE 25 TO OCTOBER 21, 1970[3]

(µg F/g)

Exposure/location	White pine		Scotch pine		Ponderosa pine	
	1969	1970	1969	1970	1969	1970
Plant shelters						
Site 1	16.5	10.6	34.5	12.6	36.1	9.8
Site 2	8.3	16.7		12.4	39.6	10.7
Site 3	18.3	25.3	23.5	8.7	46.1	10.5
Garden plots						
Site 1	7.3	7.8	10.0	5.5	19.1	7.1
Site 2	11.4	9.1		7.1	14.3	6.9
Site 3	12.7	6.2	6.3	5.0	16.6	6.8
Site 4	18.5	14.2	14.3	8.2	19.0	9.4
Control shelters[a]	6.1	5.1	9.2	4.2	15.5	5.6

[a] Fluoride content of the plants in both control shelters.

Table 14. FLUORIDE ACCUMULATION IN ALFALFA LEAVES AND STEMS EXPOSED IN 1970 STUDY[3]

Exposure/location	Fluoride content, μg F/g	
	July 24 through September 14	September 14 through October 21
Plant shelters		
Site 1	13.9	13.6
Site 2	12.5	11.5
Site 3	11.1	15.1
Garden plots		
Site 1	21.3	
Site 2	19.3	
Site 3	24.7	
Site 4	32.1	
Control plant shelters	4.4	5.0

Table 15. FLUORIDE ACCUMULATION IN CHINESE APRICOT LEAVES EXPOSED IN 1970 STUDY[3]

Exposure/location	Fluoride content, µg F/g	
	July 14 through September 14	September 14 through October 21
Plant shelters		
Site 1	6.7	15.9
Site 2	8.4	24.3
Site 3	10.7	19.7
Garden plots		
Site 1	10.2	14.6[a]
Site 2	9.9	
Site 3	9.6	
Site 4	12.8	
Control plant shelters	2.6	2.0

[a] Date of exposure was July 14 to September 26.

Table 16. FLUORIDE ACCUMULATION IN GLADIOLUS LEAF TISSUE EXPOSED FROM JUNE 25 TO SEPTEMBER 14, 1970[3]

Exposure/location	Fluoride content, μg F/g		
	0 to 2 inches from tip	2 to 4 inches from tip	4 to 6 inches from tip
Plant shelters			
Site 1	20.6	6.7	8.1
Site 2	24.0	12.4	9.3
Site 3	23.9	9.9	10.2
Garden plots			
Site 1	26.8	10.1	7.5
Site 2	43.6	9.1	8.9
Site 3	28.2	10.9	9.0
Control plant shelters	12.0	8.9	5.2

Table 17. FLUORIDE CONCENTRATION IN SOILS, SINGLE SAMPLES[4]

Sampling zone	Fluoride, ppm
1. Teakettle Mountain	540
2. Columbia Falls	168
3. Coram	217
4. Lake Five	408
7. South Fork	245
8. Middle Fork	235
9. North Fork	113
11. Headquarters Hill	235
12. Belton Hills	245
13. Apgar Ridge and MFRS	118
14. Apgar Lookout	275
Control (MacDonald Pass)	250

All sample collections were made in late August 1971, to correspond with the second sampling of 1970. Two pounds of foliage were collected from each of two conifer species, one or two shrub species, one forb, and one grass species on each plot. Conifer branches were cut to include three years' foliage from each tree sampled. Although tree species were not constant from plot to plot, the species were basically the same as those collected in 1970. Each sample was placed in a clean plastic bag and taken to the Forest Service laboratory in Missoula, Montana, for examination and analysis.

Conifer foliage was sorted by year of origin (1969, 1970, or 1971), and the injury index (I.I.) was measured separately for each year's foliage. Foliage of each year was then dried, ground, and analyzed chemically for available fluoride. The 1971 foliage of shrubs, herbs, and grasses was chemically analyzed for available fluoride, but injury index was not measured.

Fluoride analyses of Forest Service samples collected in the 1970 studies were performed by WARF. All samples collected in 1971 were chemically analyzed in the Forest Service laboratory in Missoula, Montana. Samples were not washed; thus the determinations reflect accumulation in the plant tissue of particulate as well as gaseous fluoride.

The ion specific electrode method, using Orion fluoride and reference electrodes was used by the Forest Service for analysis of 1971 samples. In addition, fluoride analyses by this method were performed on 110 samples analyzed by WARF in 1970. This experiment demonstrated that results from the two laboratories

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were comparable; linear regression analysis of paired data yielded a correlation coefficient of 0.98.[2]

A summary of results of the 1971 Forest Service investigations appears in Appendix C. The tabulation compares 1970 and 1971 results obtained from those plots that were resampled in 1971. Data for injury index and fluoride accumulation demonstrate that vegetation in the study area was being affected by fluorides in 1971. Vegetation from all plots sampled in 1971 contained concentrations of fluoride higher than those in control samples. Even visible injury was detected in vegetation collected as far as 6 miles from the aluminum plant. On the whole, however, both fluoride accumulation and injury index were lower in samples collected in 1971 than in those collected in 1970. Estimated isopol lines constructed from the 1971 data appear in Figure 13. A comparison of the areas included within the 1970 and 1971 estimated isopols is presented in Table 18. This comparison reveals that substantial reductions in areas affected in the midrange of fluoride accumulation (20 to 60 ppm fluoride) occurred between the 1970 and the 1971 samplings. The total area affected by fluoride pollution (10 ppm or more), and the areas affected by extreme values (over 100 ppm), underwent only modest reductions in the 1-year interval.

The 1971 investigation permitted examination of changes in fluoride concentrations in conifer needles over the 1-year interval between samplings. In the 1971 sampling, foliage was obtained from trees sampled in the 1970 studies. The indicated incremental accumulation over the 1-year interval in needles

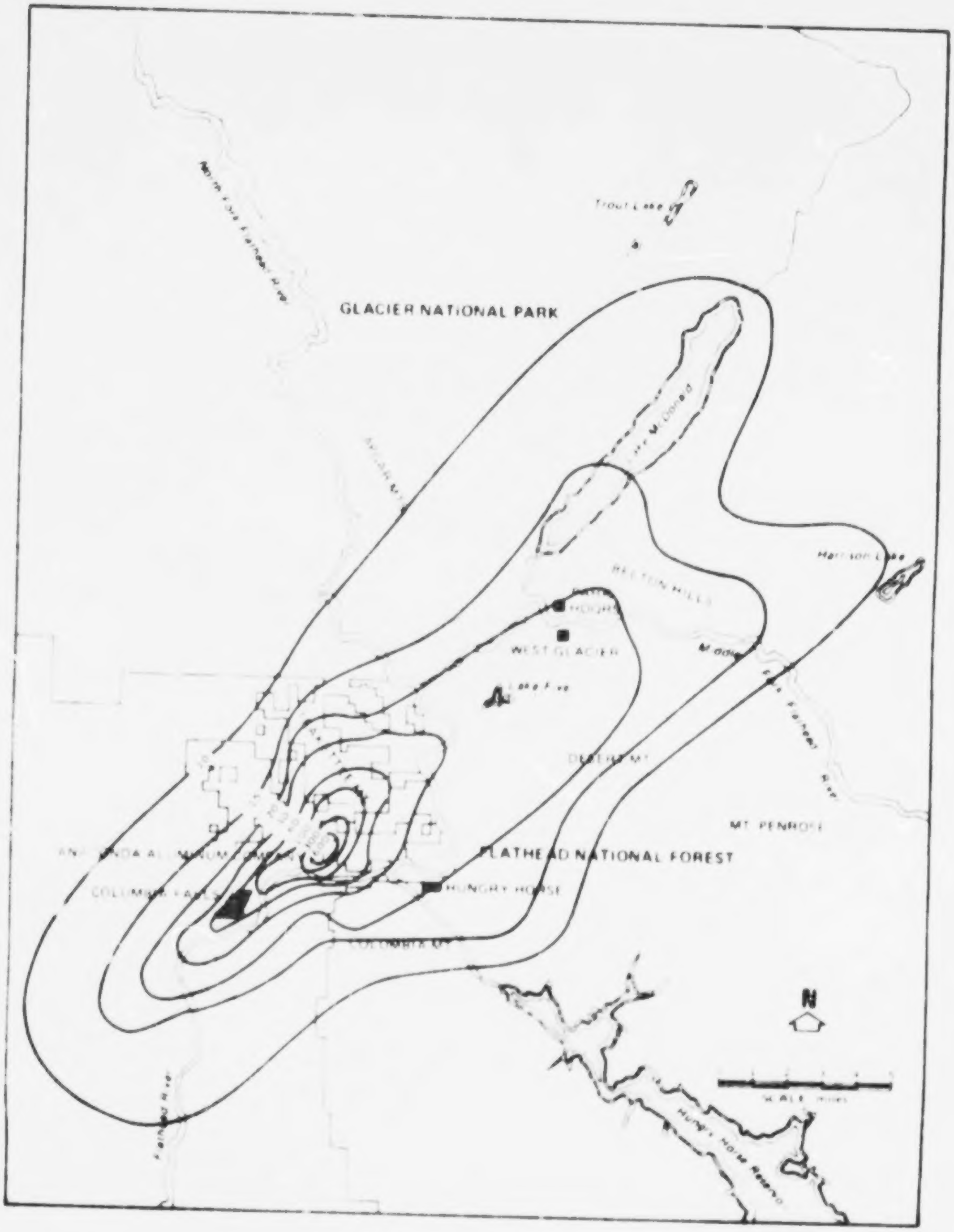
Trout Lake
North Fork Flathead River
GLACIER NATIONAL PARK
Lake McDonald
Harrison Lake
BELTON HILLS
WEST GLACIER
Lake Five
Middle Fork Flathead River
DESERT MT
MT. PENROSE
ANACONDA ALUMINUM COMPANY
FLATHEAD NATIONAL FOREST
COLUMBIA FALLS
HUNGRY HORSE
COLUMBIA MT
N
SCALE miles
Flathead River
Hungry Horse Reservoir

Figure 13. Isopols of fluoride pollution in vegetation from Forest Service data, 1971.[2]

Table 18. AREAS INCLUDED WITHIN ESTIMATED ISOPOLS OF FLUORIDE CONCENTRATION IN VEGETATION, FOREST SERVICE DATA 1970[1] AND 1971[2]

Isopol, ppm fluoride	Area Within Isopol, square miles	
	Year 1970	Year 1971
10	334	280
15	272	140
20	191	62
30	108	23.8
60	31	12
100	11	5.2
300	2	1.5
600	1	0.75

which originated in 1969 was highly variable, ranging from -116 to 88 ppm fluoride, with a mean value of 3 ppm, for the 14 radial plots sampled. The incremental accumulation in needles which originated in 1970 was less variable; accumulations over the 1-year interval in the 14 plots ranged from -31 to 157 ppm fluoride with a mean value of 41.5 ppm in the 1970 needles. Higher values of accumulation generally occurred in samples from plots located near the aluminum plant.

Follow-up studies on the impact of fluorides on flora and fauna in a portion of the study area were conducted in 1971 by the Environmental Studies Laboratory, University of Montana, for the Superintendent of Glacier National Park.[15] Three sampling zones, Headquarters Hill (Number 11), Belton Hills (Number 12), and Apgar Ridge and Middle Fork Ranger Station (Number 13), were selected for the 1971 investigations. The boundary between the Headquarters Hill and Belton Hills sampling zones was shifted slightly for the 1971 studies; samples from a small hill nearby Park Headquarters, which was included in the Belton Hills zone in 1970, were included with the Headquarters Hill samples in the 1971 studies. The 1971 studies included collection of foliage from many of the same trees sampled during the 1971 studies.

In the 1971 studies, coniferous vegetation was collected on the following listed schedule:

11. Headquarters Hill - mid-June, early November
12. Belton Hills - mid-August, mid-October
13. Apgar Ridge and MFRS - mid-July, mid-October

Data on fluoride content of foliage from these collections are presented in Appendix D and are summarized in Table 19. The results clearly demonstrate the accumulation of fluoride in vegetation during the intervals from summer 1970 to summer and fall 1971, and during the intervals between collections in summer 1971 and fall 1971. The fluoride content of needles that originated in 1969 typically increased by 25 to 35 percent of the 1970 level between summer 1970 and fall 1971; content of needles that originated in 1970 increased by 100 to 200 percent over the 1970 values. Increases in mean fluoride content of new needles, those which originated in 1971, were mostly in the order of 60 to 70 percent in the interval from summer to fall 1971; samples from one zone showed an increase of more than 100 percent over the interval. Results of the 1971 ESL studies demonstrate that fluoride continued to accumulate in conifer foliage in Glacier National Park from 1970 to 1971 despite reduction of fluoride emissions from the aluminum plant. The ESL findings are consistent with those of the Forest Service; 1-and 2-year-old needles yielded fluoride concentrations of about 10 to 20 ppm, and the sampling zones from which they came lie generally between the 15 and 20 ppm isopleths of the Forest Service studies. Further, in both the ESL and the Forest Service studies, the increase from in fluoride concentrations in 1970 needles in the period 1970 to 1971 was substantially greater than the increase in 1969 needles from the same trees over the same time interval.

Table 19. MEAN FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE FROM SELECTED SAMPLING ZONES IN 1970 AND 1971[15]

Zone	Species	Fluoride concentrations, ppm										Increase in fluoride, %		
		Summer 1970 Collection			Summer 1971 Collection				Fall 1971 Collection			Summer 1970 to Fall 1971		Summer 1971 to Fall 1971
		Needle Year			Needle Year				Needle Year			Needle Year		Needle Year
		1968	1969	1970	1968	1969	1970	1971	1969	1970	1971	1969	1970	1971
11 Headquarters Hill	Lodgepole pine	32.8	14.2	5.4	33.0	19.2	12.1	4.8	19.2	11.5	7.8	35%	112%	63%
	Ponderosa pine	34.0	17.2	4.3	30.2	21.2	11.1	3.8	21.0	12.7	6.5	22%	195%	71%
12 Belton Hills	Lodgepole pine	26.4	10.8	4.0	33.0	16.2	11.3	5.4	18.6	12.8	8.6	72%	220%	59%
13 Apgar Ridge & MFRS	Ponderosa pine	27.0	12.7	3.6	30.1	19.1	9.5	3.9	16.2	10.1	8.9	28%	181%	128%

ANIMAL STUDIES

MAMMALS

Approximately 300 animal specimens were collected from the study area by the Environmental Studies Laboratory in 1970, and bones were analyzed for fluoride content. Seventy-five control animals were obtained from areas in Montana remote from the study area. A summary of results of fluoride analyses of femur bones of all animal specimens and controls appears in Appendix E. Mean fluoride concentrations in femur bones of six major species collected from the various sampling zones are given in Table 20, and the means for these species for the entire study area are depicted in Figure 14.

Only in deer and grouse did the average fluoride concentrations in femur bones of control specimens exceed 200 ppm; the mean value for deer is 225 ppm and for grouse 209 ppm. With the single exception of deer in the North Fork sampling zone (Zone 9), the mean concentrations of fluoride in femur bones of animal specimens collected in the study area exceeded those in control animals. Further, the ratio of fluoride concentrations in bones of animals from the study area to those in bones of animals from control areas was in all cases greater than the ratio of fluoride concentrations in vegetation from the study area to concentrations in vegetation from control areas.

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Table 20. MEAN FLUORIDE CONCENTRATION IN FEMUR BONES OF ANIMALS FROM STUDY AREA SAMPLING ZONES, ENVIRONMENTAL STUDIES LABORATORY, 1970[14]

		Fluoride concentrations, ppm by weight					
	Zone	Deer	Deer Mouse	Snowshoe Hare	Chipmunk	Squirrel	Grouse
1.	Lower Teakettle Mt.	3933	1768			2403	1200
2.	Columbia Falls	2007	938		1000	1171	
3.	Coram	2270	1068	837	4666	929	1413
4.	Lake Five		1067	830	887	627	
5.	Columbia Mt				694		
6.	Desert Mt.				613		
7.	South Fork				331		
8.	Middle Fork	1280		1020	299	374	
9.	North Fork	168	541		462	222	
11.	Headquarters Hill	1720	532	253	702	324	
12.	Belton Hills				740	343	
13.	Apgar Ridge & MFRS			1619	3394	743	
14.	Apgar Lookout	582		582	295	480	
15.	Boehm's Bear Den			625	415		
16.	Lake McDonald	1807		382			
17.	Camas Creek			382	164		
19.	Loneman Mt.				367	420	
	Controls	225	107	83	109	105	209

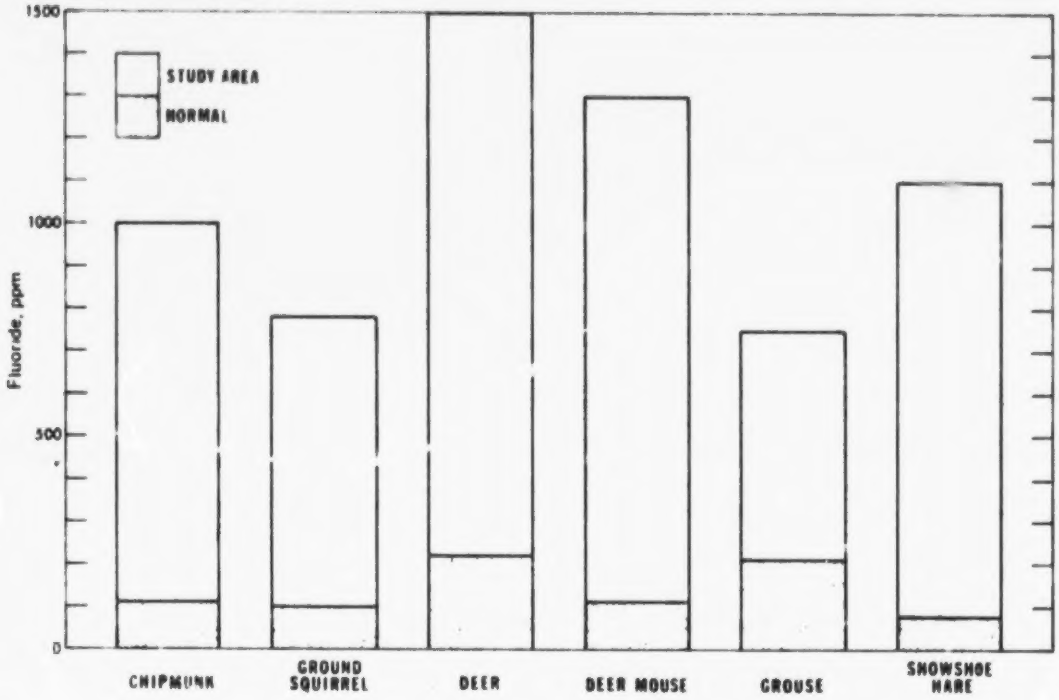

Figure 14. Average bone fluoride content.[4]

Among all zones in the study area, the highest fluoride concentrations were found in specimens collected in the Teakettle Mountain, Columbia Falls, and Coram zones, those zones nearest to the aluminum reduction plant. This parallels similar findings of high fluoride concentrations in vegetation in these three zones. For these zones, mean fluoride concentrations in femur bones of animal specimens exceeded those in control animals by factors of 10 to 40.

The highest fluoride concentrations in femur bones of animals collected from any zone within Glacier National Park were found in those from the Apgar Ridge and MFRS zone.

Bones from animals from this zone yielded mean fluoride concentrations in the range of 7 to 30 times greater than those of control animals. The average fluoride concentration in snowshoe hares from this zone was about 20 times greater than that in controls; the average in chipmunks was 30 times greater than that in controls.

Results of the fluoride analyses demonstrate that the amounts of fluoride accumulated can vary considerably among the species. These differences can be attributed to differences in life span, diet, and seasonal activity of each species.

Additional animals were collected by ESL in 1971 from three sampling zones in Glacier National Park.[15] Data on fluoride in femur bones from the six major species are presented in Table 21. The results are consistent with those from the 1970 samplings of the same zones, except for ground squirrels in the Belton Hills zone and chipmunks in the Apgar Ridge and MFRS zone. Five ground squirrels taken in the Belton Hills zone in 1971 yielded a mean value about 4 times greater than that from two specimens taken from the same zone in 1970. Nineteen chipmunks taken in the Apgar Ridge and MFRS zone in 1971 yielded a value lower by a factor of 5 than did the 5 chipmunks taken there in 1970. Comparison of the results from 1970 and 1971 specimens suggests that any changes in fluoride concentrations in forage consumed by indigenous animals over the 1-year interval 1970-1971 are not reflected in changes in fluoride content of femur bones.

Table 21. FLUORIDE CONCENTRATIONS IN FEMUR BONES OF INDIGENOUS WILD ANIMALS, SELECTED SPECIES, ENVIRONMENTAL STUDIES LABORATORY, 1971[15]

Zone	Species	Number of specimens	Fluoride concentration, ppm		
			Mean	Maximum	Minimum
11. Headquarters Hill	Deer	3	1720	2400	1040
12. Belton Hills	Chipmunk	2	904	954	854
	Ground Squirrel	5	1391	1920	690
13. Apgar Ridge and MFRS	Chipmunk	19	623	2218	136
	Ground Squirrel	20	655	1422	203
	Deer Mouse	15	453	775	272
	Grouse	4	819	1360	324
	Snowshoe Hare	4	1771	2940	284

The mean concentrations of fluoride in femur bones for all six of the major species taken in the Glacier National Park sampling zones in 1971 exceeded control values for the same species by factors of 4 to 20.

INSECTS

In the course of its investigations in 1970 the Forest Service examined both the accumulation of fluorides by insects, and changes in insect populations that might be related to fluoride accumulation in vegetation in the study area. Insects covering a broad spectrum including foliage feeders, cambium feeders, pollinators, and predators were sampled and analyzed for fluoride accumulation. At least 5 grams of each species was collected, oven dried, and sent to WARF for analysis of available fluoride. Insects were collected on June 1, August 12, and October 9, 1970. All collections were made within 1/2 mile of the aluminum plant except for eight control samples taken at least 50 miles from the plant. Results of analyses for fluoride accumulation in insects appear in Appendix F

In general, at least twice as much fluoride was found in test samples as in corresponding control samples. Foliage feeders collected within the areas sustaining fluoride pollution yielded from 21.3 to 48.6 ppm fluoride, weevils containing the highest concentrations. The cambial feeding group gave 8.5 to 52.5 ppm fluoride, engraver beetles sustaining the largest amount. Highest concentrations in the pollinating groups were found in bumblebees, 406 ppm, and the lowest in the wood nymph butterfly, 58 ppm. Bumblebees from the study area yielded fluoride concentrations greater than control values by factors of 25 to 50, the highest ratio of all species sampled. For honeybees the sample-control ratio was more than 20. Fluoride concentrations in predaceous insects ranged from 6.1 to 170 ppm fluoride, ants accumulating the largest amount.

Two forest insects, larch casebearer and pine needle scale, were sampled in an attempt to relate population numbers to fluoride accumulations in vegetation. Control samples were taken 30 miles to the north, south, east, and west of the aluminum plant. Populations of larch casebearer were measured using the system described by Bousfield,[16] in which casebearers per 100 larch spurs are counted. Populations of pine needle scale were measured by a modification of the method reported by Fischer,[17] in which scales per linear inch of "new" and "old" foliage are counted. In this study the number of scales per 600 needles were counted.

To determine whether insect populations were increasing, decreasing, or remaining static in relation to distance from the fluoride source and to foliar fluoride content, sampling was conducted in mid-April 1970 for populations of larch casebearer and pine needle scale along the established sampling radii. Sample intervals were 1/4, 1/2, 1, 2, 4, and 8 miles from the aluminum plant. Results of these samplings appear in Appendix F.

The larch casebearer samples gave no discernible pattern. Relatively high casebearer counts were found at all distances from the aluminum plant, with the exception that at the 1/4 mile distance the only larch sample taken had no casebearer.

With the exception of the 8-mile samples, scale counts on lodgepole pine generally decreased with increasing distance from the aluminum plant. Scale counts on lodgepole pine were compared with measurements of foliar fluoride content of conifers on the same plot. Linear regression analysis showed no significant correlation (r = 0.201, 30 degrees of freedom). The regression line is shown in Figure 15. An increase in scale numbers with increasing fluoride concentrations is indicated. Although the correlation is not statistically significant, the curve does suggest a trend that might be confirmed by more extensive sampling.

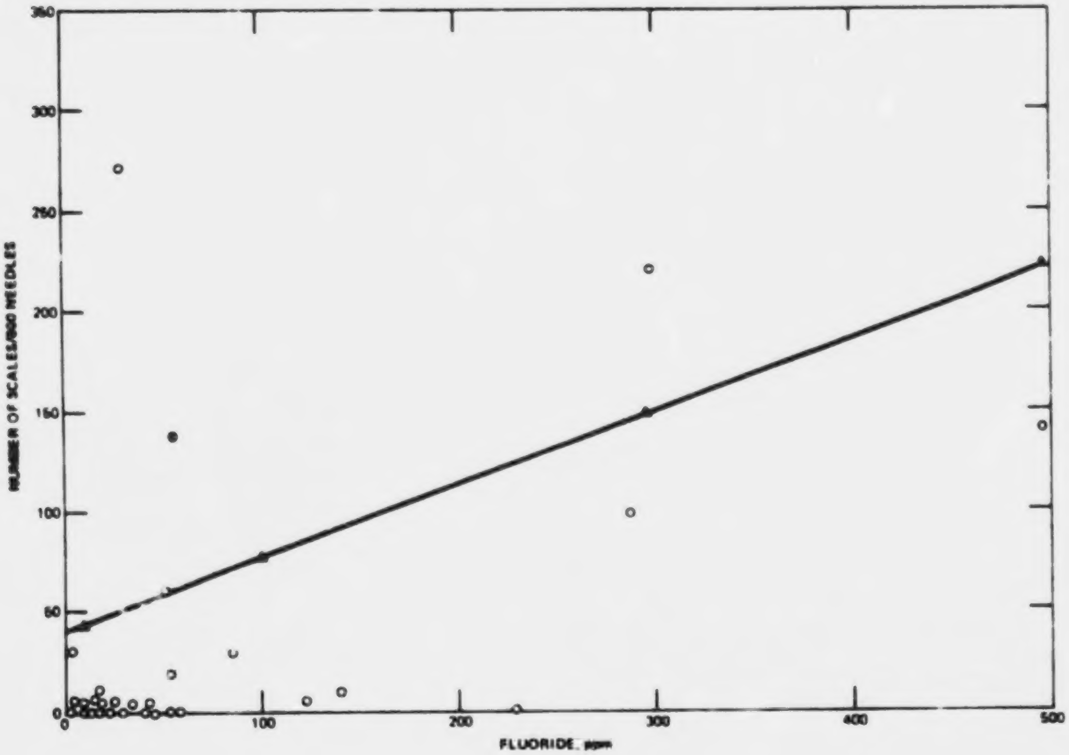

Figure 15. Relation of numbers of pine needle scales per 600 needles to fluoride content, ppm. Forest Service Studies, 1970[1]

Lodgepole pine that had scale counts exceeding 50 per 600 needles contained 23 to 401 ppm fluoride (mean 133 ppm); for pines with less than 50 scales per 600 needles the range was 6 to 160 ppm fluoride (mean 36 ppm).

The same pattern appeared for the Ponderosa pine samples, even though the number of samples was smaller.

In its 1971 investigations the Forest Service repeated collections of insects for fluoride analysis.[2] Nine insect samples, all from within 1/2 mile of the aluminum plant, were collected in mid-August 1971. The collection included pollinators, including mixed Hymenoptera, wood nymph butterflies, skipper butterflies, and mixed Syrphidae; predators, including robberflies and dragonflies; and foliage feeders, including Arctiidae larvae and Notodontidae larvae. Each was chemically analyzed, unwashed, for available fluoride by the same procedure used for vegetation samples collected in 1971. Results of the analyses appear in Appendix F.

Fluoride accumulations in insects were similar to those found in 1970. All were greater than accumulations in the control samples. Pollinators contained the most fluoride, ranging from 81.3 ppm in Erynnis sp. to 585 in mixed Hymenoptera. Predators, such as Asilidae, dragonflies, and damselflies, accumulated from 21.7 to 82.9 ppm fluoride, and foliage feeders had from 168 to 255 ppm.

DISCUSSION AND CONCLUSIONS

Through the combined efforts of several agencies and institutions the characteristics and magnitude of a specific air pollution problem in Flathead County, Montana, have been identified. The findings of the comprehensive investigations summarized in this report may give insights into similar air pollution situations in other locations. In this specific case, one major source of fluoride air pollutants, the Anaconda Aluminum Company aluminum reduction plant near Columbia Falls, has been shown to cause abnormally high fluoride concentrations in the tissues of plants and animals collected in the surroundings of the plant. The Environmental Studies Laboratory of the University of Montana demonstrated excessive fluoride concentrations in coniferous foliage in sampling zones having a combined area of about 375 square miles surrounding the aluminum plant. In independent investigations, the Forest Service found, on the basis of a radial sampling system centered on the aluminum plant, that the fluoride concentration of coniferous foliage exceeded control levels over an area of about 334 square miles. These two findings show remarkable agreement, and are consistent with the results of atmospheric sampling conducted by the Environmental Protection Agency in the study area.

That the source of excessive concentrations of fluorides in the vegetation and animal tissues and in the air samples is the aluminum reduction plant is confirmed by the common finding of all investigations that fluoride concentrations decrease with increasing distance from the plant. The geographic pattern of contamination of both air and plant tissue is elongated in the downwind direction of the region's prevailing winds.

Fluoride emissions from the aluminum plant were reported to have been decreased during the course of the 1970 investigations, with a high value of about 7500 pounds per day in 1970 reduced to about 2600 pounds per day in 1971. The accumulations of fluorides by coniferous vegetation during the course of the 1970 studies and as reflected in the 1971 collections do not show proportionate drops. This suggests the possible existence of a threshold concentration of atmospheric fluoride below which a decrease results in a corresponding decrease in accumulation by plants, but above which the excess concentration contributes little to the total accumulation by plants.[1] It is suggested that the accumulation of fluorides by a plant may be directly related to its physiological activity. Thus, a plant sensitive to fluorides may accumulate fluorides rapidly up to a point, at which time phytotoxic effects result in a decrease in physiological activity and a corresponding decrease in fluoride accumulation rate with increasing fluoride insult. Because the fluoride concentration at which phytotoxicity occurs may be higher in some species than in others, the physiological activity of the more resistant species would be greater and their abilities to accumulate fluorides would continue in the presence of fluoride concentrations above those at which the physiological activity of the more sensitive species is inhibited. Apparent differences in fluoride susceptibility in terms of visual burn symptoms in plants were observed in the Forest Service studies. Of the conifers, white pines were most susceptible, followed by Ponderosa pines, lodgepole pines, and Douglas firs, respectively. In determinations of fluoride content of foliage, the Environmental Studies Laboratory found a reverse order of descending concentrations for these species. When foliage samples of different species were obtained from the same sampling zones the trends in fluoride concentrations were: Douglas firs greater than lodgepole pines; lodgepole pines greater than Ponderosa pines; and Ponderosa pines greater than white pines. Both the injury and the fluoride concentrations classifications are based solely on field data and observations from independent investigations. Together, however, they show remarkable consistency with the suggestion of threshold phytotoxic effect.

A general observation can be made about the accumulation of fluorides in conifer foliage with successive years of exposure to excessive atmospheric concentrations of fluorides. With exposure to atmospheric fluoride, the highest fluoride concentrations are found in the oldest needles. Two-year-old needles show about twice the fluoride concentration of one-year-old needles. One-year-old needles have about twice the fluoride concentration of current-year needles in summer collections. The concentrations of fluoride in conifer foliage from locations where there is no discernable fluoride air pollution do not vary with the age of the needles.

That reduction in fluoride emissions is not necessarily reflected in proportionate reduction in the accumulation of fluoride in exposed plant tissue is illustrated by comparison of analytic results for foliage taken in 1970 and 1971 from the same sampling plots or the same trees. Fluoride emissions from the aluminum plant were reportedly reduced by a factor of 2 or 3 in the interval 1970-1971. The fluoride content of foliage from all Forest Service plots resampled in 1971 showed a reduction of almost 50 percent from 1970 to 1971; for those plots 6 miles or more from the plant, however, the reduction averaged less than 15 percent for the same interval of time. Similar findings are reported by the Environmental Studies Laboratory; mean fluoride concentrations of current and 1-year-old coniferous foliage taken from the same trees in 1970 and 1971 in sampling plots 6 to 8 miles from the aluminum plant were reduced by 20 percent or less.

The Environmental Studies Laboratory 1971 data also show that the fluoride concentrations in 1971 conifer foliage growing 6 to 8 miles from the aluminum plant more than doubled from summer to fall 1971. The mean concentration in 1970 foliage from the same zones increased by more than a factor of 3 in the 1-year interval between the 1970 and 1971 samplings. This suggests that excessive concentrations of atmospheric fluorides occurred during the intervening winter months and that some fluoride accumulated in conifer foliage even during the season when such foliage may be considered dormant.

During the 1970 study period it was observed that fluoride concentrations in coniferous vegetation varied substantially in collections made at different elevations in some sampling zones; higher concentrations were found in samples taken from higher elevations. Air sampling data illustrated the same phenomenon. These observations, coupled with meteorological observations for the area, lead to the conclusion that fluoride pollution from the aluminum plant impinges upon prominent topological features such as mountains and ridges, which are in the path of the transporting wind currents.

In the report of the Environmental Studies Laboratory investigations four major points concerning fluoride accumulations in vegetation are examined in some detail because of their ecological consequences.[4] First, excessive fluoride concentrations found in vegetation samples are not attributable to fluoride particulate, but to gaseous fluorides. Second, the air monitoring conducted by EPA in the study area in 1970 usually yielded concentrations below 1 part fluoride per billion parts of air (ppb). Third, after atmospheric fluorides enter the foliage of conifer and broadleaf species, a portion of the fluoride is translocated to the active stem tissues of both hardwoods and conifers, and also to the pollen of conifer cones. Fourth, and last, the fluoride accumulation in the foliage, stems, and reproductive tissues of conifer and broadleaf species is available for ingestion by the indigenous wild animals that utilize any part of these tissues in their normal diets.

With regard to the first point, the data obtained from unwashed and washed coniferous and hardwood stems collected from control areas and sampling zones 6 to 8 miles distant from the aluminum plant demonstrate that ordinarily less than 1 ppm of fluoride in these tissues can be attributed to fluoride particulate. This is further substantiated by the results of histological studies of needle necrosis in 1969 coniferous foliage from such zones. In general, necrotic needles contained less than 18 ppm of fluoride and some had less than 12 ppm. The literature on the matter, and other studies by the Environmental Studies Laboratory around aluminum plants, indicate that when fluoride concentrations of 12 to 18 ppm are found on and in needles, if any significant portion of the fluoride is in the form of particulate, then necrosis does not occur in 12- to 14-month-old needles.

This conclusion is also substantiated by data from conifer collections made in sampling zones nearby the aluminum plant during the early summer of 1970. In these zones the 1970 conifer foliage showed concentrations of 20 to 30 ppm of fluoride 1 1/2 months after emerging from the terminal bud, but most of the foliage had not become necrotic at the time of these early collections. Comparison of data from washed and unwashed samples showed that more than half of the fluoride had been removed by washing. This finding indicates that the excessive fluoride accumulation in the foliage in the more remote sampling zones comes from gaseous fluoride, which cannot be reduced by installation of pollution abatement equipment designed to remove only the particulate fluoride.

The second major point to be discussed concerns the results of the 1970 air monitoring in the study area. Although some static fluoride samplers were located in the previously mentioned "hot belts" of fluoride accumulation (3900 to 4400 feet elevation), most of the monitoring devices were located at an elevation of about 3100 feet. Regardless of whether the samplers were located in the hot belts or lower, the results indicate that atmospheric fluorides seldom exceeded a level of 1 ppb in Glacier National Park during the 1970 study period. It is known that certain species of pines manifest needle necrosis when exposed to a fluoride concentration of 1 ppb for 200 hours.[12] Fluoride resulting from exposure to hydrogen fluoride is a cumulative substance in plant tissues. When it is present in the ambient air at concentrations ranging from even 1/10 to 1/40 of the level of 1 ppb, it has the potential to be detrimental to the health of some plant species.

The third major point relates to the previously unreported phenomenon of fluoride translocation from the leaf to other plant tissues. Even though further investigations are needed to determine exactly which of the active stem tissues the fluorides are translocated to, and in what form they are stored, several points can be cited now as a result of these studies.

It has been known for some time that fluorides taken in from the ambient air by the leaves or needles of plants are not equally distributed throughout the foliar tissues, but migrate and accumulate in greater concentrations in the outer edges of the leaves or, in the case of conifer needles, in the apical or terminal portions of the needles. Thus, the first tissues to succumb to excessive fluoride accumulation are the outermost tissues of the leaves and needles.

The data on fluoride accumulation in the tissues of conifer stems and pollen indicate that the fluorides are concentrating at much higher levels in the pollen tissues than in the stem tissues. Although the ecological and physiological import of this discovery is not known at this time, the knowledge that fluoride can inhibit several metabolic processes that normally occur in these reproductive tissues should encourage investigators to study this potentially serious problem.

The fact that fluoride is translocated from the needles of conifers to the active tissues of stems may explain the abnormal and excessive stem growth of conifers reported by Treshow in his study of fluoride pollution in and around a phosphate plant in Idaho.[18] Since excessive fluorides are known to cause hypertrophy or cell enlargement of thin-walled cells in conifer needles, there is a possibility that excessive fluoride concentrations found in conifer stems collected from the study area could also cause cell enlargement or hypertrophy of the thin-walled cells of the young, developing stems.

Effects of the translocation of fluoride from the recipient needles and leaves to the stems and apical meristems should be the subject of further research, since the results of the current Environmental Studies Laboratory and Forest Service studies show clearly that atmospheric fluorides taken in by plants do not remain solely in the leaf and needle tissues.

The fourth and last point relates to the ingestion by animals of vegetation containing fluorides. In collections of vegetation from zones more than 6 or 8 miles from the aluminum plant, most of the samples of the current year's growth yielded fluoride concentrations substantially lower than those found in samples from zones near the plant. Yet the fluoride concentrations in animals collected from the remote zones were 1/3 to 1/2 of those found in animals from the zones nearby the aluminum plant.

Many of the animal species utilized in this study do not hibernate and therefore feed on the stems of herbaceous shrubs and on coniferous browse during the winter months. Winter and spring months are wet; so most of the fluoride particulate is probably washed off the vegetation during this time. Thus, wild animals feeding in the Coram zone, the West Face of Teakettle Mountain zone, and the southwest zones of Glacier Park are all feeding on a diet of vegetation which, in winter and spring months, accumulates similar concentrations of fluoride.

This explanation is somewhat substantiated by review of data on fluoride concentrations found in washed stems of vegetation collected from all the different zones of the study area. Results of analysis of plant tissues other than conifer needles also indicate that the indigenous wild animals in the southwest zones of Glacier National Park have little access to any type of vegetation that does not contain excessive fluorides.

The main objective in the animal portion of the studies was to ascertain whether excessive concentrations of fluoride were accumulating in the animals living in the study area. Collections of animals from the study area have confirmed conclusively that excessive fluoride concentrations were indeed accumulating in the animals. To what degree this problem affects the various animal species, and how extensive is the area affected could not be fully determined.

Most of the animals taken in Glacier National Park were not collected where vegetation had accumulated the highest fluoride concentrations, that is at the elevations of 3800 to 4400 feet in the southwestern sampling zones. Instead, the animals were taken primarily at the lower elevations between 3100 and 3500 feet. Therefore, data on excessive fluoride concentrations in the animals collected do not reflect the upper limits that could be found in animals from the Park.

The accumulation of fluorides by insects collected in the study area was demonstrated by the Forest Service. Bumblebees collected in the summer had more than twice the fluoride levels of those collected in the spring. In two instances where both larvae and adults of the same species (flathead beetles and ostomids) were analyzed, accumulation of fluorides was much higher in the adults than in the larvae. Both cases suggest that accumulation occurs throughout the life of the insects.

Damsel flies and ostomids are solely predatory in both larval and adult stages. Fluoride accumulated in insects of these species collected in the study area must have come from other insects upon which they fed, an indication that fluoride is passed along the food chain to predators.

Many plants are dependent upon insect pollinators for seed production. By altering the pollinator complex, i.e. bumblebees, honeybees, sphinx moths, and others, it is possible to alter vegetational types, and subsequently much of the ecology of an area. Studies have shown that fluorides are devastating to honeybees. If fluorides are harmful pollinators in general, fluoride pollution could have a detrimental effect on fruit trees, legumes, and many other insect-pollinated flowering plants in the area.

It is clear that excessive fluoride concentrations occurred in the flora and fauna of the Flathead County study area in 1970 and 1971. A comparison of fluoride concentrations found in vegetation and in animal species confirms that an increase of several orders of magnitude can occur in the food chain. The apparent tendancy toward concentration of fluorides in the food chain, as evidenced by results of these studies, suggests that excessive fluoride accumulation in the carnivores of the study area is a strong possibility.

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APPENDIX A

FOREST SERVICE VEGETATION DATA, 1970 STUDIES

Table A-1. RADIAL SAMPLING AND CONTROL DATA, FIRST SAMPLING

Plot	Average fluoride content, ppm dry weight						Injury Index	
	Shrubs	Conifers		Herbs	Grasses	Grand Ave.	Ave.	High
		1969	1970					
Control 1	5.65	6.25	9.25	6.67		6.92	0.003	0.006
Control 2	5.0	3.5	7.5	5.0	1.3	4.79	0.0	0.0
Control 3	11.4	7.58	6.28	10.0	9.8	8.02	0.0	0.0
Control 4	7.5	10.0	11.0	8.5	8.5	10.36	0.0	0.0
Control 5	7.17	4.75	6.77	12.0		7.03	0.007	0.014
Control 6	4.77	6.33	3.00	5.50	16.0	5.80	0.005	0.006
R1-P1[a]	108.5	300	40.8	188	70.0	122.36	0.138	0.235
R1-P2	106.5	107.8	18.3		45.0	70.72	0.305	0.442
R1-P3	48.8	42.2	11.4		18.8	31.94	0.044	0.090
R1-P4	19.8	18.3	14.7	12.5	2.5	15.46	0.132	0.301
R1-P5	17.0			16.0	8.0	12.88	0.0	0.0
R1-P6	3.0	12.5	9.0		4.0	8.94	0.0	0.0
R1-P7	6.3	5.8	9.3		4.0	6.80	0.0	0.0
R2-P1	42.4	143.5	17.5	93.8	66.3	91.21	0.075	0.313
R2-P2	112.7	127.5	20.0	90.0	83.3	89.59	0.196	0.528
R2-P3	44.3	77.9	17.8	50.0	49.0	50.21	0.163	0.313
R2-P4	13.2	20.7	8.83		13.0	14.71	0.079	0.200
R2-P5	13.0	9.5	17.3	9.0	32.0	15.86	0.012	0.019
R2-P6	3.6	5.5	2.3	5.5	2.5	3.70	0.0	0.0
R2-P7	7.1	8.9	9.2	7.3	6.0	8.13	0.004	0.008
R3-P1	1166.6			875.5	775	1004.3	0.020	0.027
R3-P2	488	637	229	315	344	411.3	0.107	0.271
R3-P3	149.0			115	3.0	118.6	0.009	0.021
R3-P4	100.0	96.0	16.0		82.5	78.90	0.136	0.136
R3-P5	37.2	31.5	11.5		22.5	26.31	0.066	0.334
R3-P6	10.0	10.8	10.9		2.1	9.23	0.0	0.0
R3-P7	14.5	7.0	8.0	3.3		8.20	0.0	0.0
R4-P1	704.2			628.0	156	604.14	0.025	0.076
R4-P2	778.0			450.5	231	537.60	0.010	0.063
R4-P3	425.5	681.5	116.5	525	206	397.25	0.072	0.500
R4-P4	120.0	198.4	65.1	96.5	234	130.23	0.150	0.470
R4-P5	21.2	57.2	15.3	34.5	49.0	38.16	0.066	0.215
[b]R4-P6	14.0	9.77	7.50	10.0	13.0	10.13	0.003	0.007
[b]R4-P7	13.7	17.8	6.83	17.8		13.25	0.038	0.051
[b]R4-P8	15.4	18.0	7.15	9.9	103	19.68	0.003	0.003
[b]R4-P9	8.0	11.2	6.0	15.5	71.5	16.98	0.0	0.0
[b]R4-P10	9.27	8.93	4.0	5.7	5.8	6.88	0.008	0.008

a) R = Radius No., P = Plot No.
b) Located on Glacier National Park lands.

Table A-1 (continued).

RADIAL SAMPLING AND CONTROL DATA, FIRST SAMPLING

Plot	Average fluoride content, ppm dry weight						Injury Index	
	Shrubs	Conifers 1969	Conifers 1970	Herbs	Grasses	Grand Ave	Ave	High
R5-P1	1719			1038	250	1181.5	0.288	0.580
R5-P2	653			375	600	597.8	0.029	0.029
R5-P3	173.7	341.0	45.0	281	444	224.2	0.197	0.343
R5-P4	137.5	243.7	68.6	70.0	87.5	130.7	0.086	0.392
R5-P5	25.0	45.9	9.60	22.5	6.0	27.80	0.151	0.344
R5-P6	20.0	30.2	12.7		21.0	19.93	0.007	0.023
R5-P7	16.1	30.5		11.5	23.5	19.60	0.003	0.006
[b]R5-P8	20.50	19.15	10.2	21.0	26.0	17.43	0.006	0.011
[b]R5-P9	20.25	29.75	11.0	13.5	72.5	24.33	0.115	0.115
[b]R5-P10	11.05	10.1	4.10	8.28	5.5	7.46	0.0	0.0
R6-P1		1950		363	313	875.3	0.202	0.442
R6-P2	1125.3			431	581	877.6	0.019	0.089
R6-P3	115.3	292	29.8	163	68.8	138.2	0.019	0.083
R6-P4	57.0	85.0	33.0	63.3	36.0	51.17	0.106	0.209
R6-P5	33.8	20.6	7.5	29.2	24.5	23.0	0.073	0.146
R6-P6	17.1	37.5	8.5	20.8	37.0	21.4	0.0	0.0
R6-P7	7.5	19.0	10.5	11.0	15.0	11.75	0.0	0.0
[b]R6-P10	14.65	13.5	6.0	18.5	51.5	17.83	0.0	0.0
R7-P1	1073			600	338	871.7	0.065	0.299
R7-P2	881.3			103	233	596.0	0.118	0.230
R7-P3	65.3	168	22.3	62.5	75.0	68.67	0.091	0.225
R7-P4	55.0	111.0	18.9	44.0	44.0	63.20	0.058	0.111
R7-P5	25.3			25.5	42.0	29.50	0.0	0.0
R7-P6	4.8	16.2	5.3	14.0	20.5	10.87	0.016	0.029
R7-P7	17.3	10.0	4.5	7.0	21.0	12.43	0.0	0.0
R8-P1	399.8	975	175		110	409.8	0.052	0.11[illegible]
R8-P2	129	245	136.5	235	65.0	152.3	0.016	0.046
R8-P3	83.3	119.8	22.5	150		85.9	0.176	0.400
R8-P4	25.3	49.0	12.7	41.5	14.3	29.4	0.087	0.152
R8-P5	20.0	31.8	9.8	14.0	8.0	17.2	0.018	0.049
R8-P6	21.5	14.9	16.0	18.3		17.8	0.0	0.0
R8-P7	11.8	14.2	9.2	13.3	22.5	12.6	0.016	0.018
R9-P1	108.7	110	39.5	51.5	41.0	70.97	0.026	0.026
R9-P3	26.1		10.0	15.0	13.5	20.40	0.0	0.0
R9-P4	43.4	58.7	24.0		23.5	45.31	0.005	0.005
R9-P5	12.5	7.8	11.0		6.0	9.80	0.0	0.0
R9-P6	11.4	9.3	5.37	6.5	9.5	7.72	0.0	0.0
R9-P7	5.6	9.0	10.3	25.0	5.0	9.98	0.0	0.0
R10-P1	76.5	133	42.5	31.0	38.5	66.3	0.032	0.097
R10-P2	43.3	61.0	14.5	45.0	22.5	38.2	0.070	0.091
R10-P3	23.3	28.8	6.3	20.8	8.5	18.9	0.013	0.022
R10-P4	22.8	20.8	9.3		16.0	16.82	0.054	0.054
R10-P5	15.0	23.9	7.8	10.0	7.5	15.0	0.0	0.0
R10-P6	11.4	11.5	10.8		10.0	10.8	0.003	0.003
R10-P7	6.8	9.2	3.5	11.0	6.5	7.54	0.0	0.0

b) Located on Glacier National Park lands.

Table A-2. RADIAL SAMPLING AND CONTROL DATA, SECOND SAMPLING

Plot	Average fluoride content, ppm dry weight						Injury Index	
		Conifers						
	Shrubs	1969	1970	Herbs	Grasses	Grand Ave	Ave	High
Control 1	8.7	8.5	4.5	10.0	11.5	8.67	0.0	0.0
Control 2	6.8	7.0	5.8	10.5	5.5	6.88	0.0	0.0
Control 3	15.8	11.3	4.75	6.5	7.5	7.91	0.0	0.0
Control 4	10.9	5.9	5.2	17.0	17.0	9.74	0.0	0.0
Control 5	10.5	7.8	5.2		16.0	8.50	0.0	0.0
Control 6	5.7	6.0	4.8	10.0	12.5	6.46	0.0	0.0
R1-P1	323	338	115	310	139	258	0.079	0.086
R1-P2	140.5	131.7	38.9	115	102	95.3	0.052	0.143
R1-P3	65.5	40.7	19.3	32.0	20.0	40.9	0.003	0.003
R1-P4	43.3	18.5	12.8	43.5	20.5	23.4	0.024	0.024
R1-P5	11.5	9.0	6.0		5.0	8.60	0.0	0.0
R1-P6	13.8	9.10	6.2			9.06	0.0	0.0
R1-P7	9.0	4.5	5.5		5.0	5.90	0.0	0.0
R2-P1	136	189	64.7	61.5	93.5	111.0	0.063	0.093
R2-P2	147.5	100.8	26.8	146	44.5	92.6	0.211	0.279
R2-P3	110.0	124.7	32.8	104	32.0	85.3	0.093	0.104
R2-P4	29.1	17.3	8.5		18.5	22.2	0.0	0.0
R2-P5	16.0	16.0	9.5	14.5		13.6	0.018	0.032
R2-P6	9.0	9.3	8.5	16.0	8.8	9.48	0.0	0.0
R2-P7	9.8	8.5	5.5	8.8	4.5	7.84	0.0	0.0
R3-P1	1194	488	258	794	600	754.7	0.281	0.348
R3-P2	475	496.5	367.8	463	101	401.2	0.313	0.628
R3-P3	281.5	294.5	70.0	137	168	199.6	0.156	0.313
R3-P4	130	85.5	23	107	68	90.6	0.034	0.043
R3-P5	49.8	42.8	17.5	36.5	31.5	33.9	0.014	0.025
R3-P6	15.0	11.8	7.5	5.5	12.5	11.0	0.008	0.015
R3-P7	7.3	12.5	10.0	7.5	4.5	8.2	0.0	0.0
R4-P1	925			1250	469	903.2		
R4-P2	1244			638	205	832.8		
R4-P3	900.5	390.3	87.5	363	385	432.8	0.208	0.495
R4-P4	211.5	286.3	123.2	375	153	215.8	0.119	0.301
R4-P5	47.5	53.3	22.2	11.5	20.0	35.3	0.075	0.211
[b]R4-P6	32.5	11.7	9.3	15.5		17.5	0.0	0.0
[b]R4-P7	21.3	11.0	9.7	23.5	14.5	15.3	0.007	0.007
[b]R4-P8	37.8	22.3	8.0	13.5		20.0	0.003	0.003
[b]R4-P9	14.3	9.8	6.3	10.5	51.5	15.3	0.0	0.0
[b]R4-P10	10.5	6.2	6.1	5.5	4.3	6.3	0.005	0.005
R5-P2	1300			875	200	918.7		
R5-P3	294.5	537.5	80.3		508	332.2	0.132	0.250
R5-P4	202.5	228.7	55	111	128	160.0	0.063	0.114
R5-P5	59.5	56.5	23.3	270	51.0	66.91	0.014	0.014
R5-P6	38.0	35.0	11.7	59.5	32.0	30.3	0.003	0.003
R5-P7	39.0	28.5	10.0	34.0	19.5	28.3	0.0	0.0
[b]R5-P8	73.0	18.0	13.0		23.5	24.5	0.0	0.0
[b]R5-P9	69.0	24.8	14.2	32.5	22.0	26.9	0.014	0.019
[b]R5-P10	12.8	11.9	10.2	9.0	15.5	11.6	0.0	0.0

b) Located on Glacier National Park lands.

Table A-2 (continued)

RADIAL SAMPLING AND CONTROL DATA, SECOND SAMPLING

	Average fluoride content, ppm dry weight						Injury Index	
		Conifers						
Plot	Shrubs	1969	1970	Herbs	Grasses	Grand Ave	Ave	High
R6-P1	1433	1728	775	2100	469	1339	0.150	0.150
R6-P2	1089			3000	488	1831		
R6-P3	169.5	239.6	44.7	171	117	148	0.114	0.144
R6-P4	64.2	140	76.3	113	53.0	83.8	0.182	0.291
R6-P5	67.3	27.0	10.3	47.0	27.5	36.7	0.006	0.006
R6-P6	54.0	32.5	13.8	14.0	21.0	32.2	0.0	0.0
R6-P7	14.8	18.8	9.8	23.5	27.5	17.2	0.0	0.0
[b]R6-P10	20.5	18.5	9.3	30.5	154	30.9	0.0	0.0
R7-P1	1509			700	375	1120		
R7-P2	969	1825	413	56.0	293	754.2	0.289	0.567
R7-P3	154.5	142.5	31.3	143	160	120.0	0.105	0.154
R7-P4	100.5	104.7	17.5		63.5	76.7	0.064	0.064
R7-P5	47.3	51.5	20.5	28.5	16.5	25.3	0.042	0.042
R7-P6	35.0	37.8	18.9	25.0	13.0	26.2	0.004	0.005
R7-P7	23.0	14.0	10.2	17.2	7.5	14.3	0.002	0.002
R8-P1	812.5	906	306	750	131	619.7	0.0	0.0
R8-P2	475.5	313	209.5	325	70.0	269.9	0.0	0.0
R8-P3	199.0	167.0	41.3	250	97.5	145.2	0.042	0.067
R8-P4	48.5	56.0	55.3	32.5		49.3	0.0	0.0
R8-P5	33.5	28.1	14.5	31.5	14.5	24.1	0.0	0.0
R8-P6	26.3	15.5	8.8	14.5	42.5	19.5	0.0	0.0
R8-P7	16.2	14.0	8.50		12.5	12.7	0.0	0.0
R9-P1	251.5	168	76	198	85	171.7	0.0	0.0
R9-P2	134.7			113	132	129.8		
R9-P3	45.0	19.3	12.3	52.5	35.0	30.1	0.0	0.0
R9-P4	68.0	41.5	14.0	35.8	33.0	39.0	0.0	0.0
R9-P5	9.0	4.5	4.75	8.5	6.0	5.79	0.0	0.0
R9-P6	17.3	4.7	4.27	14.0		9.48	0.0	0.0
R9-P7	10.5	4.0	6.03		5.5	6.29	0.0	0.0
R10-P1	185.5	140	62.0	200	76.0	141.5	0.030	0.030
R10-P2	107.7	51.5	23.5	77.5	72.5	78.3	0.0	0.0
R10-P3	30.7	23.0	8.8	26.0	28.5	24.6	0.0	0.0
R10-P4	41.8	16.5	15.5	31.0	24.0	26.6	0.0	0.0
R10-P5	9.5	20.8	10.5	33.8	12.5	17.41	0.004	0.004
R10-P6		12.3	5.0		11.0	10.1	0.0	0.0
R10-P7		4.7	4.4	7.0	8.0	5.74	0.0	0.0

b) Located on Glacier National Park lands.

Table A-3. AREA POLLUTED BY FLUORIDES, ALL LANDS STUDIES

	Within Radial System				Outside Radial System[a]				Total			
	Area Greater[b]		Area Between Isopols[c]		Area Greater		Area Between Isopols		Area Greater		Area Between Isopols	
Isopol	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres
10	222	142,080			112	71,680			334	213,760		
			48	30,720			14	8,960			62	39,680
15	174	111,360			98	62,720			272	174,080		
			63	40,320			18	11,520			81	51,840
20	111	71,040			80	51,200			191	122,240		
			39	24,960			44	28,160			83	53,120
30	72	46,080			36	23,040			108	69,120		
			52	33,280			25	16,000			77	49,280
60	20	12,800			11	7,040			31	19,840		
			12	7,680			8	5,120			20	12,800
100	8	5,120			3	1,920			11	7,040		
			6	3,840							9	5,760
300	2	1,280			--	--			2	1,280		
			1	640							1	640
600	1	640			--				1	640		

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[a] The area Southwest of Columbia Falls

[b] Total area sustaining greater than a given level of fluoride, ppm.

[c] Area between estimated isopols, i.e., the area between the 10 and 15 isopols, etc.

Table A-4. FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
Columbia Falls	1[a]	Larch	69	220			
	2[a]	Ponderosa pine	69	40			
	3[a]	Ponderosa pine	68	175			
	4[a]	Lodgepole pine	69	85			
	5[a]	Lodgepole pine	68	290			
	6[a]	Ponderosa pine	68	155			
	7[a]	Norway maple	69	150			
	2a[a]	Lodgepole pine	69	53.5			
	2b[a]	Lodgepole pine	68	71.0			
	3a[a]	Lodgepole pine	69	69			
	3b[a]	Lodgepole pine	68	60			
	15a[a]	Ponderosa pine	69	1.0			
	15b[a]	Ponderosa pine	68	29.5			
Columbia Mountain	12a[a]	Lodgepole pine	69	19.0			
	12b[a]	Lodgepole pine	68	86.5			
	14a[a]	Douglas fir	69	31.5			
	14b[a]	Douglas fir	68	43.0			
	3	Lily of valley	70	25.5		0.340	
	4	Douglas fir	70	12.0	16.0	0.011	0.00
		Douglas fir	69	31.0	33.5	0.008	0.00
	5	Ponderosa pine	70		13.0		0.00

[a] Collected in 1969; no measurement of injury index. All other samples were collected in 1970.

Table A-4 (continued). **FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES**

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
Teakettle Mountain		Ponderosa pine	69		35.5		0.16
	6	Ponderosa pine	70	6.3	17.0	0.00	0.00
		Ponderosa pine	69	41.3	45.5	0.122	.003
	20	Lodgepole pine	70	20.5	23.0	0.00	0.098
		Lodgepole pine	69	120.0	139	0.512	0.005
	21	White pine	70	24.5	52.0	0.00	0.007
		White pine	69	118.0	158	0.229	0.216
	22	Ceanothus	70	190		0.137	
	23	Douglas fir	70	45.5	145	0.269	0.150
		Douglas fir	69		500		1.105
	24	Ponderosa pine	70	30.5		0.123	
		Ponderosa pine	69	124		0.721	
	25	Lodgepole pine	70	44.0	91.0	0.000	0.179
		Lodgepole pine	69	300	781	0.193	0.326
	26	Ribes Sp.	70	563		0.301	
	27	Douglas fir	70	86.0	125	0.259	0.00
		Douglas fir	69		481		0.00
		Douglas fir	68	1163		0.010	
	28	Pine grass	70	438	14.0		
	29	Ceanothus	70	450	244	0.092	
	30	Lodgepole pine	70	26.0	13.5	0.002	0.00
		Lodgepole pine	69	92.5	58.0	0.081	0.014

Table A-4 (continued). FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
	31	White pine	70	16.8	77.5	0.000	0.000
		White pine	69	99.0	117	0.001	0.000
	32	Lodgepole pine	70	11.0	22.0	0.000	0.101
		Lodgepole pine	69	156.0	71.0	0.218	0.299
	33	White pine	70	56.3		0.104	
		White pine	69	180	135	0.177	0.196
	37-A	Mt. Maple	70		425		
	38-A	Lodgepole pine	70		57.5		0.80
		Lodgepole pine	69		363		0.414
	40-A	White pine	70		43.0		0.006
		White pine	69		41.5		0.003
	41	Ponderosa pine	70		16.5		0.000
		Ponderosa pine	69		63.0		0.000
	42	White pine	70		18.0		0.000
		White pine	69		45.0		0.166
	43	Ponderosa pine	70		7.5		0.001
		Ponderosa pine	69		25.5		0.000
	44	White pine	70		9.0		0.000
		White pine	69		27.0		0.000
Glacier Park	11a[a]	Lodgepole pine	70	10.0			
	11b[a]	Lodgepole pine	69	65.0			
	8a[a]	Lodgepole pine	70	1.0			
	8b[a]	Lodgepole pine	69	29.0			

Table A-4 (continued). FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
	9a[a]	Lodgepole pine	70	11.0			
	9b[a]	Lodgepole pine	69	21.0			
	9	Oregon Grape	70	9.0		0.102	
	11	Lodgepole pine	70	3.3	11.5	0.005	0.000
		Lodgepole pine	69	15.0	31.0	0.175	0.000
	12a	Ceanothus	70	11.0	11.5	0.013	
	15	Douglas fir	70	7.3	15.0	0.000	0.000
		Douglas fir	69	28.0	36.0	0.122	0.051
	16	Douglas fir	70	13.0		0.000	
		Douglas fir	69	66.3		0.330	
	33.5	Lodgepole pine	70	5.3	12.0	0.000	0.000
		Lodgepole pine	69	21.3	23.5	0.010	0.004
	34	Ponderosa pine	70	6.3	5.0	0.000	0.000
		Ponderosa pine	69		17.0	0.029	0.000
	35	Ponderosa pine	70	5.5	6.5	0.000	0.000
		Ponderosa pine	69	10.0	18.0	0.000	0.002
	48	Lodgepole pine	70		10.5		0.000
		Lodgepole pine	69		27.5		0.002
Coram Experimental Forest	1	Pine grass	70	15.0	12.0		
	2	Serviceberry	70	14.3	26.3	0.001	
	3	White pine	70	6.0	8.0	0.000	0.000
		White pine	69	27.5	18.5	0.023	0.000
	4	Larch	70	10.5	10.0	0.006	0.000

Table A-4 (continued). FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
	5	Pine grass	70	11.0	15.5	0.000	
	6	Serviceberry	70	20.0	21.3	0.004	
	7	White pine	70	6.0	11.5	0.000	0.000
		White pine	69	24.0	7.0	0.055	0.000
	8	Larch	70	8.0	8.5	0.000	0.000
	9	Pine grass	70	5.0	7.5		
	10	Serviceberry	70	10.5	12.0	0.005	
	11	White pine	70	8.0	7.5	0.000	0.000
		White pine	69	9.5	9.5	0.000	0.000
	12	Larch	70	6.0	7.5	0.000	0.000
	13	Pine grass	70	7.8	13.8		
	14	Serviceberry	70	9.5	12.0	0.005	
	15	White pine	70	17.5	4.0	0.007	0.000
		White pine	69	15.5	7.0	0.007	0.000
	16	Larch	70	16.3	10.5	0.007	0.000
Hungry Horse Reservior	13a[a]	Lodgepole pine	70	2.0			
	13b[a]	Lodgepole pine	69	12.0			
	12b	White pine	70	9.0		0.000	
		White pine	69	5.0		0.000	
	13	White pine	70	2.0	7.5	0.000	0.000
		White pine	69	5.0	9.5	0.000	0.000
	14	White pine	70	6.0	4.0	0.000	0.000
		White pine	69	9.0	8.5	0.000	0.000

Table A-4 (continued). FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride content, ppm		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
	17	White pine	70	6.3	7.5	0.000	0.000
		White pine	69	11.5	10.5	0.010	0.000
	18	White pine	70	7.5	8.5	0.000	0.000
		White pine	69	29.5	24.0	0.062	29.5

APPENDIX B

ENVIRONMENTAL STUDIES LABORATORY VEGETATION DATA, 1970 STUDIES

Table B-1. FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE

(ppm by weight in dry needles)

		Lodgepole pine			Ponderosa pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
West Face Teakettle Mountain Zone No. 1	No. samples	13	13	13	4	5	5	7	7	7			
	Mean	310.3	146.4	19.4	211.0	116.2	22.2	140.4	75.4	14.7			
	Maximum	668	345	61.8	410	292	43.0	225	125	26.0			
	Minimum	33	13.5	3.9	105	31.0	4.5	37.0	23.0	7.4			
	Std. dev.	212	109	18.4	138	104	16.4	75.5	33.8	6.3			
	95 Percentile	688[a]	341	52.3	536	338	57.2	287	141	26.9			
	99 Percentile	879	439	68.7	838	506	83.7	378	182	34.5			
Columbia Falls Zone No. 2	No. samples	6	7	7	28	28	28				22	22	22
	Mean	76.5	36.3	16.9	97.1	50.7	24.0				114.2	65.8	38.9
	Maximum	116	54.0	31.0	192	96.0	52.4				182	110	78.0
	Minimum	30.6	19.2	10.8	18.2	11.5	5.0				32.8	24.8	18.2
	Std. dev.	31.8	12.6	6.7	41.3	22.4	10.7				46.5	24.1	14.7
	95 Percentile	141	60.8	29.9	167.	88.8	42.2				194	107	62.1
	99 Percentile	184	75.9	38.0	199	106	50.5				231	126	73
Coram Zone No. 3	No. samples	32	32	32	12	13	13	16	16	16	2	2	1
	Mean	90.0	47.5	7.6	47.0	19.8	4.9	60.9	40.2	10.0	73.5	39.0	3.5
	Maximum	520	260	20.5	120	41.0	13.5	225	90.0	23.0	93.0	49.0	
	Minimum	24.0	13.5	3.9	16.0	10.0	2.6	12.8	14.9	3.9	54.0	29.0	
	Std. dev.	119.3	56.2	4.1	28.3	9.0	3.3	49.6	24.5	5.6	27.6	14.1	
	95 Percentile	292	143	14.5	97.8	35.8	10.8	148	83.1	19.8	248	128	
	99 Percentile	379	183	17.5	124	43.9	13.7	190	104	24.6	952	488	

a) Percentile values calculated using student's t-distribution.

Table B-1 (continued). FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE

(ppm by weight in dry needles)

		Lodgepole pine			Ponderose pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Lake Five Zone No. 4	No. samples	15	14	15	8	8	8				1	1	1
	Mean	26.3	13.1	5.1	20.6	12.4	4.0				23.0	17.0	7.3
	Maximum	38.0	21.8	8.2	26.0	16.5	5.8						
	Minimum	19.0	7.0	3.1	14.0	9.9	2.3						
	Std. dev.	6.1	4.2	1.3	3.7	2.5	1.3						
	95 Percentile	37.0	20.5	7.4	27.6	17.1	6.46						
	99 Percentile	42.3	24.2	8.5	31.7	19.9	7.90						
Columbia Mountain Zone No. 5	No. samples	5	5	5	6	6	6	9	9	9	1	1	1
	Mean	8.6	4.2	2.7	40.5	21.4	9.2	5.9	4.8	3.4	14.0	8.3	6.3
	Maximum	14.2	5.5	3.7	79.0	38.5	18.5	14.5	7.3	7.0			
	Minimum	3.4	2.7	2.0	7.9	7.6	4.5	3.5	3.4	1.5			
	Std. dev.	5.0	1.2	0.7	34.2	14.9	5.1	3.4	1.4	1.6			
	95 Percentile	19.3	6.8	4.2	109.4	51.4	19.5	12.2	7.4	6.4			
	99 Percentile	27.3	8.7	5.3	155.6	71.5	26.4	15.7	8.9	8.0			
Desert Mountain Zone No. 6	No. samples	9	9	9	13	13	13	8	8	8			
	Mean	17.6	7.8	4.1	17.7	8.3	3.6	11.0	7.5	3.8			
	Maximum	34.0	18.0	7.6	30.5	13.0	7.0	21.0	12.0	5.5			
	Minimum	6.5	2.7	1.5	7.4	3.7	1.9	4.3	4.0	1.8			
	Std. dev.	9.7	4.5	2.3	7.1	3.5	1.5	5.3	2.9	1.2			
	95 Percentile	35.6	16.2	8.4	30.4	14.5	6.3	21.0	13.0	6.0			
	99 Percentile	45.7	20.8	10.8	36.7	17.7	7.6	26.9	16.2	7.3			

Table B-1 (continued). FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE
(ppm by weight in dry needles)

		Lodgepole pine			Ponderose pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
South Fork Zone No. 7	No. samples	3	3	3	7	7	7	7	7	7			
	Mean	18.0	9.2	2.7	16.0	9.6	4.0	9.6	6.2	3.6			
	Maximum	33.0	17.0	4.5	26.0	15.0	7.5	15.0	9.1	6.3			
	Minimum	6.4	3.8	1.6	3.9	2.9	2.7	3.6	2.4	1.6			
	Std.dev.	13.6	6.9	1.6	8.2	4.4	1.6	4.7	2.7	1.8			
	95 Percentile	57.7	29.3	7.4	31.9	18.1	7.1	18.7	11.4	7.1			
	99 Percentile	112.7	57.2	13.8	41.8	23.4	9.0	24.4	14.7	9.3			
Middle Fork Zone No. 8	No. samples	10	10	10				3	3	3			
	Mean	13.5	6.7	3.8				4.3	3.4	2.5			
	Maximum	29.5	11.0	5.2				5.2	3.7	3.5			
	Minimum	3.2	3.2	2.5				3.5	3.0	1.7			
	Std. dev.	9.7	2.7	0.7				0.9	0.4	0.9			
	95 Percentile	31.3	11.6	5.1				6.9	4.6	5.1			
	99 Percentile	40.9	14.3	5.8				10.6	6.2	8.8			
North Fork Zone No. 9	No. samples	11	11	11	2	2	2	10	10	10			
	Mean	11.0	5.7	4.1	9.5	6.4	3.9	10.2	6.3	5.2			
	Maximum	20.5	9.7	7.2	11.0	7.0	4.0	14.0	9.0	9.0			
	Minimum	4.8	3.3	2.4	8.0	5.8	3.7	5.6	4.3	3.1			
	Std. dev.	4.5	1.9	1.3	2.1	0.8	0.2	3.3	1.7	1.8			
	95 Percentile	19.2	9.14	6.5	22.8	11.5	5.2	16.2	9.4	8.5			
	99 Percentile	23.4	11.0	7.7	76.3	31.9	10.3	19.5	11.1	10.3			

Table B-1 (continued). FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE
(ppm by weight in dry needles)

		Lodgepole pine			Ponderose pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Doris Mountain Zone No. 10	No. samples	4	4	4	8	8	8	6	6	6			
	Mean	4.5	2.7	3.5	11.5	6.1	3.7	4.5	3.6	2.7			
	Maximum	6.2	3.4	7.8	44.5	14.5	6.7	5.5	4.1	4.2			
	Minimum	3.2	2.2	1.5	3.5	2.5	1.7	3.9	2.6	2.0			
	Std. dev.	1.3	0.5	2.9	13.9	4.1	1.6	0.7	0.5	0.8			
	95 Percentile	7.6	3.9	10.3	37.8	13.9	6.7	5.9	4.6	4.3			
	99 Percentile	10.4	5.0	16.7	53.2	18.4	8.5	6.9	5.3	5.4			
Headquarters Hill Zone No. 11	No. samples	13	13	13	10	10	10	5	5	5	2	2	2
	Mean	30.8	14.3	5.1	28.9	17.7	4.3	22.7	13.9	4.7	51.0	21.7	8.0
	Maximum	42.0	21.3	9.8	40.0	26.0	8.7	31.0	29.0	6.4	54.0	24.4	12.0
	Minimum	20.5	7.0	2.3	20.5	13.0	2.0	14.0	6.9	3.0	48.0	19.0	4.0
	Std. dev.	7.0	3.6	2.3	6.4	3.9	2.1	6.7	8.8	1.2	4.2	3.8	5.7
	95 Percentile	42.9	20.5	9.1	40.6	24.8	8.2	37.0	32.7	4.7	77.5	45.7	44.0
	99 Percentile	49.6	24.0	11.3	47.0	28.7	10.2	47.8	46.9	9.2	184.6	142.6	189.4
Belton Hills Zone No. 12	No. samples	15	15	15	5	5	5	5	5	5			
	Mean	30.0	12.7	4.8	29.2	14.6	4.5	15.7	9.5	5.2			
	Maximum	40.0	17.5	6.7	39.0	19.0	6.7	22.0	12.5	8.6			
	Minimum	16.3	6.4	1.9	16.0	10.4	3.1	8.3	5.0	1.5			
	Std. dev.	7.5	3.9	1.4	8.7	3.8	1.4	4.9	3.2	2.5			
	95 Percentile	43.2	19.6	7.3	47.7	22.7	7.5	26.1	16.3	10.5			
	99 Percentile	49.7	22.9	8.5	61.8	28.8	9.8	34.1	21.5	14.6			

Table B-1 (continued). **FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE**

(ppm by weight in dry needles)

		Lodgepole pine			Ponderose pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Apgar Ridge and MFRS Zone No. 13	No. samples	14	14	14	13	14	14	7	7	7			
	Mean	31.0	12.4	4.6	26.7	13.3	4.2	16.0	8.5	5.8			
	Maximum	59.0	23.0	7.7	51.0	27.0	7.5	23.0	13.0	8.0			
	Minimum	10.0	3.3	2.3	15.0	7.1	2.5	9.1	6.0	2.3			
	Std. dev.	15.0	6.7	1.8	9.0	5.5	1.5	4.8	2.3	1.9			
	95 Percentile	57.6	24.3	7.8	42.7	23.0	6.9	25.3	13.0	9.5			
	99 Percentile	70.8	30.2	9.4	50.8	27.9	8.2	33.8	17.0	12.8			
Apgar Lookout Zone No. 14	No. samples	15	15	15	5	5	5	2	2	2			
	Mean	18.9	9.1	4.4	23.5	13.5	6.6	8.9	5.5	3.0			
	Maximum	28.0	17.0	15.0	36.5	28.9	16.4	12.0	6.3	3.3			
	Minimum	11.0	4.6	1.4	18.0	9.0	2.9	5.8	4.6	2.6			
	Std. dev.	5.5	3.1	3.1	7.4	8.6	5.6	4.4	1.2	0.5			
	95 Percentile	28.6	14.6	9.9	39.3	31.8	18.5	36.7	13.1	6.2			
	99 Percentile	33.3	17.2	12.5	51.2	45.7	27.6	148.9	43.7	18.9			
Boehm's Bear Den Zone No. 15	No. samples	5	5	5	1	1	1	9	9	9			
	Mean	22.5	10.6	4.2	6.9	4.5	2.7	7.5	5.7	4.1			
	Maximum	45.0	22.0	6.5				16.0	7.4	6.2			
	Minimum	8.2	2.8	3.2				4.3	4.3	1.8			
	Std. dev.	14.4	7.3	1.4				3.8	1.1	1.6			
	95 Percentile	53.2	26.2	7.2				14.6	7.8	7.1			
	99 Percentile	76.4	38.0	9.5				18.5	8.9	8.7			

Table B-1 (continued). FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE

(ppm by weight in dry needles)

		Lodgepole pine			Ponderosa pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Lake McDonald Zone No. 16	No. samples	11	11	11				29	29	29			
	Mean	14.1	7.2	3.2				11.5	7.1	4.4			
	Maximum	28.0	14.0	5.4				24.4	17.0	8.3			
	Minimum	5.3	2.9	1.8				2.9	2.8	<1.0			
	Std. dev.	7.3	4.1	1.2				5.6	3.5	1.5			
	95 Percentile	27.3	14.6	5.4				21.0	13.1	7.0			
	99 Percentile	34.3	18.5	6.5				25.3	15.7	8.1			
Camas Creek Zone No. 17	No. samples	6	6	6	1	1	1	3	3	3			
	Mean	8.3	4.7	3.0	9.1	4.3	2.5	6.7	5.0	3.6			
	Maximum	11.0	8.5	3.8				9.3	7.1	4.8			
	Minimum	4.8	2.9	1.6				2.8	1.4	1.9			
	Std. dev.	2.1	2.0	0.9				3.4	3.1	1.5			
	95 Percentile	12.5	8.7	4.8				16.6	14.1	8.0			
	99 Percentile	15.4	11.4	6.0				30.4	26.6	14.1			
Huckleberry Mountain Zone No. 18	No. samples							6	6	6			
	Mean							7.0	4.7	3.5			
	Maximum							12.5	8.0	6.4			
	Minimum							3.8	1.4	1.5			
	Std. dev.							3.0	2.4	1.9			
	95 Percentile							13.0	9.5	7.3			
	99 Percentile							17.1	12.8	9.9			

Table B-1 (continued). FLUORIDE CONCENTRATIONS IN CONIFEROUS FOLIAGE

(ppm by weight in dry needles)

		Lodgepole pine			Ponderose pine			White pine			Douglas fir		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Loneman Mountain Zone No. 19	No. samples	3	3	3	2	2	2	6	6	6			
	Mean	5.6	3.5	2.1	8.8	4.8	2.0	5.3	4.6	2.7			
	Maximum	7.0	4.3	2.6	9.6	5.4	2.4	8.5	6.2	3.4			
	Minimum	3.6	2.9	1.5	7.9	4.3	1.6	3.1	2.2	1.7			
	Std. dev.	1.8	0.7	0.6	1.2	0.8	0.6	2.5	1.4	0.6			
	95 Percentile	10.9	5.5	3.9	16.4	9.9	5.8	10.3	7.4	3.9			
	99 Percentile	18.1	8.4	6.3	47.0	30.3	21.1	13.7	9.3	4.8			
ALL CONTROLS	No. samples	14	14	14	9	9	9	4	4	4	4	4	4
	Mean	2.2	2.6	2.1	2.6	2.2	2.0	1.8	1.9	1.8	2.1	2.6	1.6
	Maximum	3.9	5.2	4.5	5.0	3.7	2.7	3.0	3.0	2.5	2.9	4.1	1.8
	Minimum	1.0	1.0	1.0	1.1	1.2	1.1	1.1	1.1	1.1	1.7	1.5	1.5
	Std. dev.	1.1	1.1	1.0	1.3	0.9	0.6	0.8	0.9	0.6	0.6	1.2	0.2
	95 Percentile	4.2	4.6	3.9	5.0	3.9	3.1	3.7	4.0	3.2	3.5	5.4	2.0
	99 Percentile	5.1	5.5	4.8	6.4	4.8	3.7	5.4	6.0	4.5	4.8	8.0	2.5

Table B-2. FLUORIDE CONCENTRATIONS IN GRASS, 1970

Sampling zone	No. samples	Fluoride, ppm by dry weight			
		Mean	Maximum	Minimum	Std. dev.
1. Teakettle Mountain	6	87.4	275.0	16.2	96.3
2. Columbia Falls	19	149.1	410.0	48.0	94.4
3. Coram - grass	12	14.7	64.0	4.5	16.5
- hay	6	12.9	20.0	5.8	5.1
4. Lake Five	3	5.4	7.4	2.7	2.4
5. Columbia Mountain	1	14.0			
6. Desert Mountain	5	5.6	11.0	1.8	3.9
7. South Fork	3	7.1	10.0	4.8	2.6
8. Middle Fork	10	4.0	7.3	1.0	2.2
9. North Fork	7	6.3	9.3	2.7	2.3
10. Doris Mountain	1	3.8			
11. Headquarters Hill	4	7.7	12.3	4.4	3.4
12. Belton Hills	3	10.2	17.5	6.5	6.3
13. Apgar Ridge and MFRS	3	7.8	12.5	2.8	4.8
14. Apgar Lookout	3	4.8	11.0	1.6	5.3
15. Boehm's Bear Den	4	2.8	5.3	1.0	1.8
16. Lake McDonald	7	10.4	26.5	2.7	8.0
17. Camas Creek	5	5.1	6.2	3.6	1.0
19. Loneman Mountain	2	4.6	5.8	3.4	1.7
Controls	16	4.4	7.8	2.0	1.7

APPENDIX C

FOREST SERVICE VEGETATION DATA,
1971 STUDIES

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Table C-1. RADIAL SAMPLING AND CONTROL DATA, 1971

	Fluoride content, ppm							Injury Index		1-yr change[a] in average F^- concentration	
		Conifers									
	Shrubs	2-Year	1-Year	Current	Herbs	Grass	Grand Average	Average	High	1969	1970
Control											
1970	8.13	9.05	6.61	5.95	9.50	10.56	8.34	0.000	0.000	+2.44	+3.28
1971	8.45		9.23	8.55	11.20	8.00	8.91	0.000	0.000		
Diff.	+0.32		+2.62	+2.60	+1.70	-2.56	+0.57	0.000	0.000		
%	+3.90		+39.60	+43.70	+17.90	-24.20	+0.07				
R2-P2											
1970	147.50	134.10	100.80	26.80	146.00	44.50	92.6	0.211	0.279	+33.30	+62.70
1971	111.00		89.50	22.90	121.00	54.40	75.0	0.022	0.029		
Diff.	-36.50		-11.30	-3.90	-25.00	+9.90	-17.6	-0.189	-.250		
%	-24.70		-11.20	-14.50	-17.10	+22.20	-19.0	-89.600	-89.600		
R3-P3											
1970	281.50	240.00	294.50	70.00	137.00	168.00	199.6	0.156	0.313	-54.50	+68.00
1971	192.00		138.00	58.00	71.80	72.20	102.1	0.125	0.258		
Diff.	-89.50		-156.50	-12.00	-65.20	-95.80	-97.5	-0.031	-.055		
%	-31.80		-53.10	-17.10	-47.60	-57.00	-48.8	-19.900	-17.600		
R3-P4											
1970	130.00	89.00	85.50	23.00	107.00	68.00	90.6	0.034	0.043	+3.50	+42.00
1971	87.00		65.00	21.20	83.50	72.00	62.3	0.035	0.066		
Diff.	-43.00		-20.50	-1.80	-23.50	+4.00	-28.3	+0.001	+.023		
%	-33.10		-24.00	-7.80	-22.00	+5.90	-31.2	+2.900	+53.500		

[a] Conifers only; year of origin of tissue.

Table C-1 (continued). RADIAL SAMPLING AND CONTROL DATA, 1971

	Fluoride content, ppm									1-yr change[a] in average F^- concentration	
		Conifers						Injury Index			
	Shrubs	2-Year	1-Year	Current	Herbs	Grass	Grand Average	Average	High	1969	1970
R4-P2											
1970	1244.00				638.0	205.0	832.80				
1971	324.00	700.0	340.0	111.1	240.0	144.0	241.80	0.066	0.133		
Diff.	-920.0				-398.0	-61.0	-591.00				
%	-74.0				-62.4	-29.8	-71.00				
R5-P3											
1970	294.5		537.5	80.3		508.0	332.20	0.132	0.250	+32.5	+157.2
1971	284.0	570.0	237.5	50.6	126.0	220.0	172.30	0.048	0.066		
Diff.	-10.5		-300.0	-29.7		-288.0	-160.00	-0.084	-0.184		
%	-3.6		-55.8	-37.0		-56.7	-48.20	-63.600	-73.600		
R5-P4											
1970	202.2		228.7	55.0	111.0	128.0	160.00	0.063	0.114	-116.1	+15.8
1971	53.0	112.6	70.8	16.4	12.4	13.4	36.20	0.122	0.158		
Diff.	-149.2		-157.9	-38.6	-98.6	-114.6	-123.80	+0.059	+0.044		
%	-73.7		-69.0	-70.2	-88.8	-89.5	-77.40	+93.700	+38.600		
R5-P5											
1970	59.5		56.5	23.3	270.0	51.0	66.91	0.014	0.014	+9.6	+11.9
1971	64.6	66.1	35.2	12.8	32.6	41.8	33.60	0.025	0.031		
Diff.	+5.1		-21.3	-10.5	-237.4	-9.2	-33.30	+0.011	+0.017		
%	+8.6		-37.8	-45.1	-87.9	-18.0	-49.80	+78.600	+121.000		

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[a] Conifers only; year of origin of tissue.

Table C-1 (continued). RADIAL SAMPLING AND CONTROL DATA, 1971

	Fluoride content, ppm									1-yr change[a] in average F^- concentration	
		Conifers						Injury Index			
	Shrubs	2-Year	1-Year	Current	Herbs	Grass	Grand Average	Average	High	1969	1970
R5-P6											
1970	38.0		35.0	11.7	59.5	32.0	30.3	0.003	0.003	-0.9	+6.4
1971	49.2	34.1	18.1	15.8	56.2	30.0	29.0	0.036	0.036		
Diff.	+11.2		-16.9	+4.1	-3.3	-2.0	-1.3	+0.033	+0.033		
%	+29.5		-48.3	+35.0	-5.5	-6.2	-4.3				
R6-P3											
1970	169.5		239.6	44.7	171.0	117.0	148.0	0.114	0.114	+88.4	+127.3
1971	112.0	328.0	172.0	43.9	124.0	74.2	106.0	0.100	0.234		
Diff.	-57.5		-67.6	-0.8	-47.0	-42.8	-42.0	-0.014	-0.090		
%	-33.9		-28.2	-2.8	-27.5	-36.6	-28.4	-12.300	-62.500		
R6-P4											
1970	64.2		140.0	76.3	113.0	53.0	83.8	0.182	0.291	-56.4	-31.0
1971	48.0	83.6	45.3	20.9	46.0	37.2	37.7	0.029	0.033		
Diff.	-16.2		-94.7	-55.4	-67.0	-15.8	-46.1	-0.153	-0.258		
%	-25.2		-67.6	-72.6	-59.3	-29.8	-55.0	-84.100	-88.700		
R7-P3											
1970	154.5		142.5	31.3	143.0	160.0	120.0	0.105	0.154	+77.5	+90.6
1971	200.0	220.0	121.9	41.4	234.0	184.0	134.9	0.034	0.068		
Diff.	+45.5		-20.6	+10.1	+91.0	+24.0	+14.9	-0.071	-0.086		
%	+29.4		-14.5	+32.3	+63.6	+15.0	+12.4	-67.600	-55.800		

[a] Conifers only; year of origin of tissue.

Table C-1 (continued). RADIAL SAMPLING AND CONTROL DATA, 1971

	Fluoride content, ppm							Injury Index		1-yr change[a] in average F^- concentration	
	Shrubs	Conifers 2-Year	Conifers 1-Year	Conifers Current	Herbs	Grass	Grand Average	Average	High	1969	1970
R8-P5											
1970	33.5		28.1	14.5	31.5	14.5	24.1	0.000	0.000	+1.1	+3.7
1971	25.8	29.2	18.2	10.8	17.8	9.0	15.8	0.005	0.005		
Diff.	-7.7		-9.9	-3.7	-13.7	-5.5	-8.3	+0.005	+0.005		
%	-23.0		-35.2	-25.5	-43.5	-37.9	-34.4				
Col. Mt.											
1970			38.2	15.3	25.5		26.6	0.081	0.160	+11.0	+7.0
1971	44.0	49.2	22.3	19.8	72.2	12.2	28.3	0.014	0.023		
Diff.			-15.9	+4.5	+46.7		+1.7	-0.067	-0.137		
%			-41.6	+29.4	+183.0		+6.4	-82.700	-85.600		
R4-P6											
1970	32.5		11.7	9.3	15.5		17.5	0.000	0.000	+14.5	+10.0
1971	18.1	26.2	19.3	7.9	28.8	11.8	16.1	0.006	0.009		
Diff.	-14.4		+7.6	-1.4	+13.3		-1.4	+.006	+.009		
%	-44.3		+65.0	-15.1	+65.8		-8.0				
R5-P9											
1970	69.0		24.8	14.2	32.5	22.0	26.9	0.014	0.019	-1.4	+9.9
1971	20.4	23.4	24.1	11.5	29.0	10.1	18.7	0.000	0.000		
Diff.	-48.6		-0.7	-2.7	-3.5	-11.9	-8.2	-0.014	-0.019		
%	-70.4		0.0	-19.0	-10.8	-54.1	-30.5	-100.000	-100.000		

[a] Conifers only; year of origin of tissue.

Table C-1 (continued). RADIAL SAMPLING AND CONTROL DATA, 1971

	Fluoride content, ppm							Injury Index		1-yr change[a] in average F⁻ concentration	
		Conifers									
	Shrubs	2-Year	1-Year	Current	Herbs	Grass	Grand Average	Average	High	1969	1970
Total 1970	2920.40		1963.40	495.7	2000.5	1571.00	2251.91	1.109	1.784	42.10	581.50
Total Diff.	1331.30		886.20	-141.8	-831.2	-608.70	-1142.11	-0.508	-0.768		
Total 1971	1589.10	2705.5	1077.20	353.9	1169.3	962.30	1109.80	0.601	1.016		
N	14.00		14	14	14	13	15	14	14	14	14
Average Diff.	-95.10		-63.30	-10.1	-59.4	-46.80	-76.10	-0.036	-0.055	3.01	41.53
% Diff.	-45.60		-45.10	-28.6	-41.5	-38.70	-49.30	-45.800	-43.000		

[a] Conifers only; year of origin of tissue.

Table C-2. SUMMARY OF STEM ANALYSES FOR FLUORIDE CONTENT

(ppm dry weight)

Plot	Shrubs			Conifers			Herbs	Grand average
	1969	1970	1971	1969	1970	1971	1969	
Control	7.8	9.5	6.9	9.3	11.3	5.9	5.8	8.4
R2-P2	11.6	19.8	12.8	25.5	25.7	24.7	23.8	22.0
R3-P3	10.2	10.4	12.0	24.2	22.7	27.3	16.4	19.7
R3-P4	7.2	7.6	10.8	10.6	16.8	15.8	11.6	13.4
R4-P2	16.6	15.1	37.6	35.0	37.4	41.1	22.6	29.9
R5-P3	19.8	15.2	20.0	19.3	35.5	35.4		26.2
R5-P4	9.4	13.0	19.8	16.6	12.8	17.6	10.8	14.7
R5-P5	11.4	8.4	7.8	13.6	14.6	14.2	11.6	12.2
R5-P6	11.8	9.8	15.1	11.3	10.1	11.2		11.3
R6-P3	15.2	22.8	16.2	20.4	21.0	17.7	21.0	19.3
R6-P4	14.0	11.6	16.6	21.5	14.6	25.5	14.0	18.9
R7-P3	17.0	20.2	29.8	20.2	19.0	18.3	10.2	19.2
R8-P5	14.8	12.6	9.8	13.2	14.2	10.4	11.2	12.4
Col. Mt.	11.3	9.0	9.8	28.4	21.5	13.8	17.2	15.0
R5-P9	8.5	7.6	6.4	8.4	13.9	7.4	10.4	9.2
R4-P6	10.6	6.8	14.8	17.8	8.7	10.4	11.6	11.1
Veg. type average	12.69	11.57	16.85	19.46	19.74	19.39	14.80	17.10

APPENDIX D

ENVIRONMENTAL STUDIES LABORATORY VEGETATION DATA, 1971 STUDIES

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Table D-1. FLUORIDE CONTENT IN VEGETATION, 1971 STUDIES

HEADQUARTERS HILL ZONE

GP#	Species	Elev. Ft.	Fluoride, ppm			GP#	Date Collected	Fluoride, ppm				GP#	Date Collected	Fluoride, ppm			
			'68	'69	'70			'68	'69	'70	'71			'68	'69	'70	'71
99	L. Pine	4800	37.0	13.5	4.4	21	6/20/71	30.0	21.2	14.9	8.8						
255	L. Pine	4500	37.5	12.0	5.7	17	6/19/71	44.0	20.0	8.2	4.8	50	11/3/71		17.6	11.8	6.9
254	L. Pine	4480	21.5	12.0	4.5	16		25.0	15.4	7.8	4.0				Not collected		
257	L. Pine	4200	38.5	17.2	6.7	18		35.0	16.8	13.4	4.6				Not collected		
253	L. Pine	4160	35.0	15.3	6.3	15		26.8	17.0	10.6	4.8	48	11/3/71		20.6	11.2	8.2
259	L. Pine	3910	31.0	17.5	4.8	19		41.6	30.4	24.0	4.5				Not collected		
252	L. Pine	3800	33.0	14.5	5.3	14		46.0	20.4	7.8	3.2	47	11/3/71		19.6	12.4	10.6
251	L. Pine	3590	28.5	11.8	5.2	13		15.4	12.4	10.2	3.6	46		25.4	14.4	9.4	6.6
	L. Pine	4300	Not collected					Not collected				44			24.0	12.6	6.6
98	P. Pine	4700	31.0	13.5	2.7	20	6/20/71	32.0	17.6	8.8	3.6	43			21.6	10.2	6.6
	P. Pine	4300	Not collected					Not collected				44				11.6	6.0
102	P. Pine	3800	32.0	19.0	3.6	22	6/20/71	29.6	29.6	16.6	4.2	45		30.2	23.0	13.8	7.0
251	P. Pine	3580	39.0	19.0	6.7	13	6/19/71	29.0	16.4	7.8	3.6	46			16.6	10.0	4.5
	P. Pine	4200	Not collected					Not collected				51			22.6	18.0	8.2
101	D. Fir	4300	48.0	19.0	4.8			Not collected				44				6.7	6.3
	D. Fir	4200	Not collected					Not collected				51		39.0	30.0	22.0	10.4

Table D-1 (continued). FLOURIDE CONTENT IN VEGETATION, 1971 STUDIES

BELTON HILLS WINTER RANGE

GP#	Species	Elev. Ft.	Fluoride, ppm			GP#	Date Collected	Fluoride, ppm				GP#	Date Collected	Fluoride, ppm			
			'68	'69	'70			'68	'69	'70	'71			'68	'69	'70	'71
149	L. Pine	5980	31.0	14.0	6.3	1	8/16/71	40.2	20.6	13.2	6.6	33	10/15/71		18.0	12.6	11.0
150	L. Pine	5600	22.0	7.4	3.6	2	8/16/71	28.0	13.6	11.8	5.7	34			16.4	15.0	11.0
		Not collected										35			18.6	10.6	8.8
154	L. Pine	5090	21.0	7.0	1.9	6	8/16/71	22.0	12.6	9.2	4.4	36			16.4	11.2	6.6
155	L. Pine	5100	No sample									38			20.0	13.8	7.0
156	L. Pine	4450	31.5	15.0	4.3	7	8/16/71	41.8	18.2	11.0	4.8	39			22.4	13.8	7.4
149	W. Pine	5980	16.0	11.5	8.6	1	8/16/71	18.4	13.4	13.4	3.9	33			16.2	11.6	11.6
149	D. Fir	5980	No sample			1	8/16/71	62.6	34.6	13.0	9.4	33			17.0	17.4	9.8
150	D. Fir	5600	No sample				Not collected					34			20.0	16.2	11.2
	D. Fir	5500	Not collected				Not collected					35			26.0	15.6	11.6
154	D. Fir	5090	No sample				Not collected					36			18.0	12.0	9.4
155	D. Fir	5100	No sample				Not collected					38			22.0	13.2	7.8
	D. Fir	4100	Not collected				Not collected					40			22.0	12.2	7.8
	D. Fir	At river	Not collected				Not collected					42			12.2	12.0	7.0
158	P. Pine	At river	16.3	10.0	3.1	9	8/16/71	15.8	7.6	3.0		42			12.4	6.4	4.4

Table D-1 (continued). FLOURIDE CONTENT IN VEGETATION, 1971 STUDIES

APGAR RIDGE

GP#	Species	Elev. Ft.	Fluoride, ppm			GP#	Date Collected	Fluoride, ppm				GP#	Date Collected	Fluoride, ppm			
			'68	'69	'70			'68	'69	'70	'71			'68	'69	'70	'71
165	L. Pine	4190	26.0	10.5	2.8	10	7/18/71	31.0	15.2	10.0	4.2	29	10/14/71		12.6	11.0	7.1
165	P. Pine	4190	15.0	8.6	2.8	10		26.6	14.8	8.6	3.2	29			16.6	10.8	6.7
166	P. Pine	3900	38.0	18.5	4.4	11		42.6	30.0	11.6	4.6	30		42.0	24.6	12.0	7.9
167	P. Pine	3700	28.0	28.0	3.5	12		21.0	12.6	8.4	3.8	31			8.6	9.2	16.4
	P.P. (big)	At road	Not collected					Not collected				32		33.2	18.0	9.8	6.2
	P.P. (small)	At road	Not collected					Not collected				32			13.4	8.8	7.4
	Doug. Fir	At road	Not collected					Not collected				32			17.6	11.2	9.0

APPENDIX E

ENVIRONMENTAL STUDIES LABORATORY ANIMAL DATA, 1970 STUDIES

Table E-1. FLUORIDE CONCENTRATION IN FEMUR BONES OF INDIGENOUS WILD ANIMALS

Sampling zone	Species	No. Specimens	Fluoride, ppm by weight		
			Mean	Max.	Min.
Lower Teakettle Mountain Zone 1	Columbian ground squirrel	10	2403	4366	457
	Deer	17	3933	9400	370
	Deer mouse	22	1768	4243	588
	Flying squirrel	1	1617		
	Grouse	1	1200		
	Hairy woodpecker	2	361	483	238
	House cat	1	1600		
	House mouse	4	707	1421	351
	Meadow vole	1	1072		
	Shorttail weasel	1	1422		
	Sparrow	1	2052		
Columbia Falls Zone 1	Chipmunk	1	1000		
	Columbian ground squirrel	9	1171	3100	363
	Deer	5	2007	3495	1100
	Deer mouse	10	938	3857	21
	Martin	1	465		
	Meadow vole	41	518	1785	37.5
Coram Zone 3	Chipmunk	5	4666	9863	815
	Columbian ground squirrel	16	929	5199	12.4
	Deer	2	2270	3700	840
	Deer mouse	4	1068	1280	854

Table E-1 (continued). FLUORIDE CONCENTRATION IN FEMUR BONES OF INDIGENOUS WILD ANIMALS

Sampling zone	Species	No. Specimens	Fluoride, ppm by weight		
			Mean	Max.	Min.
Coram (continued) Zone 3	Grouse	5	1413	4208	538
	Snowshoe hare	3	837	2053	87.5
Lake Five Zone 4	Bushytail woodrat	1	850		
	Chipmunk	11	887	2218	265
	Columbian ground squirrel	12	627	1154	61.4
	Deer mouse	1	1067		
	Red squirrel	3	754	1511	271
	Snowshoe hare	6	830	1500	48.3
Columbia Mountain Zone 5	Chipmunk	5	694	1542	191
Desert Mountain Zone 6	Chipmunk	2	613	911	315
	Golden-mantled ground squirrel				
South Fork Zone 7	Chipmunk	1	331		
Middle Fork Zone 8	Chipmunk	2	299	454	143
	Columbian ground squirrel	6	374	648	227
	Deer	1	1280		
	Golden-namtled ground squirrel	1	256		
	Snowshoe hare	1	1020		

Table E-1 (continued). FLUORIDE CONCENTRATION IN FEMUR BONES OF INDIGENOUS WILD ANIMALS

Sampling zone	Species	No. Specimens	Fluoride, ppm by weight		
			Mean	Max.	Min.
North Fork Zone 9	Chipmunk	1	462		
	Columbian ground squirrel	1	222		
	Coyote	1	268		
	Deer	1	168		
	Deer mouse	4	541	688	210
Headquarters Hill Zone 11	Chipmunk	2	702	784	620
	Columbian ground squirrel	9	324	472	88.5
	Deer	1	1720		
	Deer mouse	2	532	640	424
	Snowshoe hare	1	253		
Belton Hills Zone 12	Chipmunk	7	470	859	190
	Columbian ground squirrel	2	343	508	178
Apgar Ridge & MFRS Zone 13	Chipmunk	5	3394	9863	107
	Columbian ground squirrel	10	735	1670	190
	Golden-mantled ground squirrel	2	782	1299	266
	Snowshoe hare	24	1619	3450	579
Apgar Lookout Zone 14	Chipmunk	3	295	367	214
	Columbian ground squirrel	1	480		

Table E-1 (continued). FLUORIDE CONCENTRATION IN FEMUR BONES OF INDIGENOUS WILD ANIMALS

Sampling zone	Species	No. Specimens	Fluoride, ppm by weight		
			Mean	Max.	Min.
Apgar Lookout (continued) Zone 14	Deer	2	582	1040	124
	Snowshoe hare	10	582	1200	234
Boehm's Bear Den Zone 15	Chipmunk	1	415		
	Snowshoe hare	1	625		
Lake McDonald Zone 16	Deer	4	1807	2400	1220
	Snowshoe hare	1	382		
Camas Creek Zone 17	Chipmunk	2	164	212	115
	Snowshoe hare	1	382		
Loneman Mountain Zone 19	Chipmunk	1	367		
	Columbian ground squirrel	1	470		
Controls	Chipmunk	16	109	304	50
	Columbian ground squirrel	16	105	146	35
	Deer	31	225	635	86
	Deer mouse	2	107	113	100
	Grouse	7	209	402	110
	Snowshoe hare	3	83	166[a]	35

a) one adult, others juvenile

APPENDIX F

FORESTS SERVICE INSECT DATA,
1970 STUDIES

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Table F-1. FLUORIDE ACCUMULATION IN INSECTS

Insect	Date Collected[a]	Fluoride, ppm	
		Sample	Control
Pollinators:			
Bumblebee-Bombus sp.	August	406.0	
Bumblebee-Bombus sp.	June	194.0	7.5
Sphinx moth-Hemaris sp.	June	394.0	
Honey bee-Apis mellifera	June	221.0	10.5
Skipper butterfly-Erynnis	August	146.0	
Wood nymph butterfly-Cercyonis sp.	August	58.0	
Foliage feeders:			
Weevils-Mixed curculionids	June	48.6	
Grasshoppers-Melanoplus sp.	August	31.0	7.5
Larch Casebearer-Coleophora laricella	June	25.5	16.5
Cicadas-Cicadidae	June	21.3	
Cambium feeders:			
Engraver beetles-Ips sp.	October	52.5	11.5
Flathead beetle-Mixed buprestids	June	20.0	3.5
Red turpentine beetle-Dendroctonus valens LeConte	June	11.5	4.8
Douglas-fir beetle-Dendroctonus pseudotsugae Hopk.	October	9.4	
Flatheaded beetle larvae-Mixed buprestids	October	8.5	
Predators:			
Ants	June	170.0	
Ostomids-Temnochila sp.	June	53.4	
Damsel flies-Argia sp.	June	21.7	9.2
Longlegged fly-Medeterus sp.	October	10.2	
Ostomid larvae	October	6.1	
Miscellaneous Insects:			
Long horned beetles-Mixed Cerambycids	August	47.5	
Click beetles-Mixed elaterids	June	36.0	
Black Scavenger-Cerambycid	June	18.8	

a) Species and control samples collected on same dates.

Table F-2. POPULATIONS OF LARCH CASEBEARER

(Casebearers per 100 larch spurs)

Miles from plant	Radii										Ave.
	1	2	3	4	5	6	7	8	9	10	
1/4											0
1/2		0	0					0	14.4	17.4	6.4
1	33.4	13.0	0						0.2	16.4	12.6
2	15.8	8.6		0				0.2	0	8.0	5.4
4	27.6	1.4	0.75	0		0	0.4	17.4		1.2	6.95
8								5.0		12.8	8.9
Ave.	25.6	5,8	0.25	0		0	0.4	5.7	4.9	11.2	

Checks: No. 1 = 8.6; No. 2 = 0; No. 3 = 0; No. 4 = 27.6

Table F-3. POPULATIONS OF PINE NEEDLE SCALES, LODGEPOLE

(Scales per 600 lodgepole needles)

Miles from plant	Radii																				Ave.	
	1		2		3		4		5		6		7		8		9		10			
	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70
1/4																						
1/2			1085	229	140	40															612	134
1	1	0	4	1	220	140															75	47
2	55	38	10	0	28	2	99	11	0	3	10	1			0	0	0	0			25	7
4	0	0	0	0	0	0	0	0	138	2	0	0	57	3	2	1			1	0	21	1
8	26	11	2	0			0	0	272	149	9	0	0	0	0	0	0	0	0	2	34	18
Ave.	20	12	220	46	97	45	33	4	137	51	6	0.3	28	1	1	0.3	0	0	0.5	1		

Checks: No. 1 = (0-0_); No. 2 = (0-0); No. 3 = (1-0); No. 4 = - Ave. = 0.3

Table F-4. POPULATIONS OF PINE NEEDLE SCALES, PONDEROSA

(Scales per 600 ponderosa needles)

Miles from plant	Radii																				Ave.	
	1		2		3		4		5		6		7		8		9		10			
	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70
1/4	365	71																			365	71
1/2					29	1													12	0	20	0.5
1	1	0	2	1											6	0	0	0	147	35	37	7
2			0	0	43	0	0	0													14	0
4															0	0			0	0	0	0
8																			0	0	0	0
Ave.	183	35	1	0.5	36	0.5	0	0							3	0	0	0	79	17		

Checks: No. 1 (6-0_); No. 2 (-); No. 3 (-); No. 4 (4-0_) Ave (5-0)